PL-TR--95-2164
Special Reports, No. 276

EARLY YEARS OF AIR FORCE GEOPHYSICS RESEARCH CONTRIBUTING TO INTERNATIONALLY RECOGNIZED STANDARD AND REFERENCE ATMOSPHERES

Kenneth S. W. Champion

24 November 1995

PHILLIPS LABORATORY
Directorate of Geophysics
AIR FORCE MATERIEL COMMAND
HANSCOM AIR FORCE BASE, MA 01731-3010

"This technical report has been reviewed and is approved for publication"

Robert A. McClatchey

ROBERT A. McCLATCHEY
PL/GPA Division Director

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 24, 1995

3. REPORT TYPE AND DATES COVERED
Scientific, final

4. TITLE AND SUBTITLE
Early Years of Air Force Geophysics Research Contributing to Internationally Recognized Standard and Reference Atmospheres

5. FUNDING NUMBERS
CRDA 95-PL-12

PE 62101F
PR 6670
TA GZ
WU 00

6. AUTHOR(S)
K.S.W. Champion*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Phillips Lab/GPA
29 Randolph Road
Hanscom AFB, MA 01731-3010

8. PERFORMING ORGANIZATION REPORT NUMBER
PL-TR-95-2164
SR, No. 276

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
*Senior Executive Service (Retired)

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Some of the research done at the Air Force Cambridge Research Center, Geophysics Research Directorate and the Air Force Cambridge Research Laboratories during the early years of the Space Program is reviewed. Vignettes are provided of some of the programs in which the laboratories were world leaders. The period starts with the testing of captured V-2 rockets at White Sands, NM in 1946 and ends with satellites that were launched in 1983. A very extensive scientific rocket program from 1956 had the goals of determining the properties of the upper atmosphere and ionosphere and, in some cases, modifying them. There was participation in many joint field programs with other organizations. When the satellite age started in 1957, AFCRC was in the forefront of supporting satellite tracking, determining drag effects on orbits, and developing first time accurate upper atmosphere models. This was followed by developing and flying unique satellites to determine atmospheric properties and providing instruments for satellites that were developed jointly with other DoD organizations and NASA. Finally, the laboratory made major contributions to the development of updated versions of the U. S. Standard Atmosphere and Supplements, and to the development of several versions of CIRA (COSPAR International Reference Atmospheres.).

14. SUBJECT TERMS
Geophysics research, Standard atmospheres, Rocket measurements
Satellite measurements, Reference atmospheres

15. NUMBER OF PAGES
64

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Contents

Illustrations

Summary

Some of the early research done at the Air Force Cambridge Research Center (AFCRC), Geophysics Research Directorate (GRD) and the Air Force Cambridge Research Laboratories (AFCRL) during the early years of the Space Program is reviewed. It is not possible to cover all the geophysics programs that existed in the early days of the laboratories, but vignettes will be provided of some of the programs in which the laboratories were World Leaders

The period starts with the testing of captured V-2 rockets at White Sands, NM in 1946 and ends with satellites that were launched in 1983. There was a very extensive scientific rocket program starting in 1956 with the goal of determining the properties of the upper atmosphere and ionosphere and, in some cases, modifying them. There was participation in many joint field programs with other organizations. These ranged from the IGY Program, PCA (Polar Cap Absorption) Program and diagnostic programs to support high altitude nuclear tests.

When the satellite age started in 1957, AFCRL was in the forefront of supporting satellite tracking, determining drag effects on orbits, and developing the first accurate upper atmosphere models. This was followed by developing and flying unique satellites to determine atmospheric properties and providing instruments for satellites that were developed jointly with other DoD organizations and NASA. The laboratory had an extensive experimental program to measure reaction rates which were important in modeling the upper atmosphere and ionosphere under natural and disturbed conditions.

Received for publication 21 November 1995

Finally, the laboratory made major contributions to the work of COESA (Committee on the Extension to the Standard Atmosphere) in the development of updated standard atmospheres and in the development of several versions of CIRA (COSPAR International Reference Atmospheres).

1. EARLY ROCKET FLIGHTS

Starting in 1946, scientists at the Cambridge Field Station, including Marcus O'Day, started firing captured German V-2 rockets at White Sands, New Mexico. Some of the rockets were instrumented with pressure gauges to measure upper atmosphere pressure. The rocket performance, as it had been in Germany, was not very reliable.

A step forward was made on March 12, 1956 when a smaller U.S.A. made Aerobee rocket was launched at 1415 local time at Holloman Air Force Base, New Mexico[1], containing 18.5 lb. of gaseous NO under pressure. The gas was released at an altitude of 95 km. Shortly after the release a high density electron cloud was detected by two radars and a C-3 ionospheric sounder for about 10 minutes. The flux of solar Lyman-alpha radiation at a wavelength of 1216A (121.6nm) is about 0.2 erg cm^{-2} and has an efficiency of about 95% to photoionize NO. This process accounts for most of the ionization in the daytime region of the ionosphere.

At 0145 local time on March 14, 1956 another Aerobee was launched carrying gaseous NO under pressure[2]. When the NO was released at about 106 km altitude a bright luminous glow appeared immediately at the release point. It gradually grew in size while diminishing in intensity, primarily due to diffusion. After 10 minutes it had an area of about 3 to 4 times the apparent size of the moon and was visible only to sensitive optical instruments. The emitted light appeared to have a continuous spectrum and the reactions involved are believed to be the following.

$NO + O \rightarrow NO_2^* + h\nu$ (continuous spectrum)

$NO_2 + O \rightarrow NO + O_2^*$

$O_2^* \rightarrow O_2 + h\nu$ (oxygen bands)

NO acts as a catalyst enabling the reassociation energy of the oxygen atoms ($2O \rightarrow O_2^*$) to be converted into visible radiation. The NO recycles and the glow persists until it is dissipated by diffusion.

These two rocket experiments were the first studies of the respective daylight and nighttime reactions of NO in the upper atmosphere.

2. IGY ROCKET PROGRAM AT FORT CHURCHILL, FEBRUARY 1957

The International Geophysical Year (IGY) was a large scale international program to study geomagnetism, the upper atmosphere and ionosphere, and other geophysical properties. One major program was to use instrumented rockets at Fort Churchill on Hudson Bay, Canada, to study atmospheric and ionospheric properties at high latitude and to study aurora at a time of maximum solar activity. Sydney Chapman, the Chairman of the IGY, flew to Churchill to spend several days with us. There was an Air Force team including me, Andy Faire, and others with the task of firing several rockets equipped with 7-inch falling spheres. These spheres, originally developed by the University of Michigan, were used to determine upper atmospheric density by measuring the drag on them as they fell after being released from a rocket at high altitude. They contained an accelerometer in which the time-of-fall of a spherical bobbin was measured, a telemetry system, electronic control circuits and a battery power supply. Figure 1 contains a photo of a mock-up of a 7-inch sphere.

For most of us it was our baptism of fire. This was particularly so when, due to a windweighting error, a first-stage Nike rocket (screamed down) quite close to where we were stationed. The weather was cold with average daily temperatures of -40^0 F. NRL and BRL (U.S. Army Ballistic Research Laboratory) participated in the program with rockets equipped with optical instruments and other sensors to measure particle fluxes and

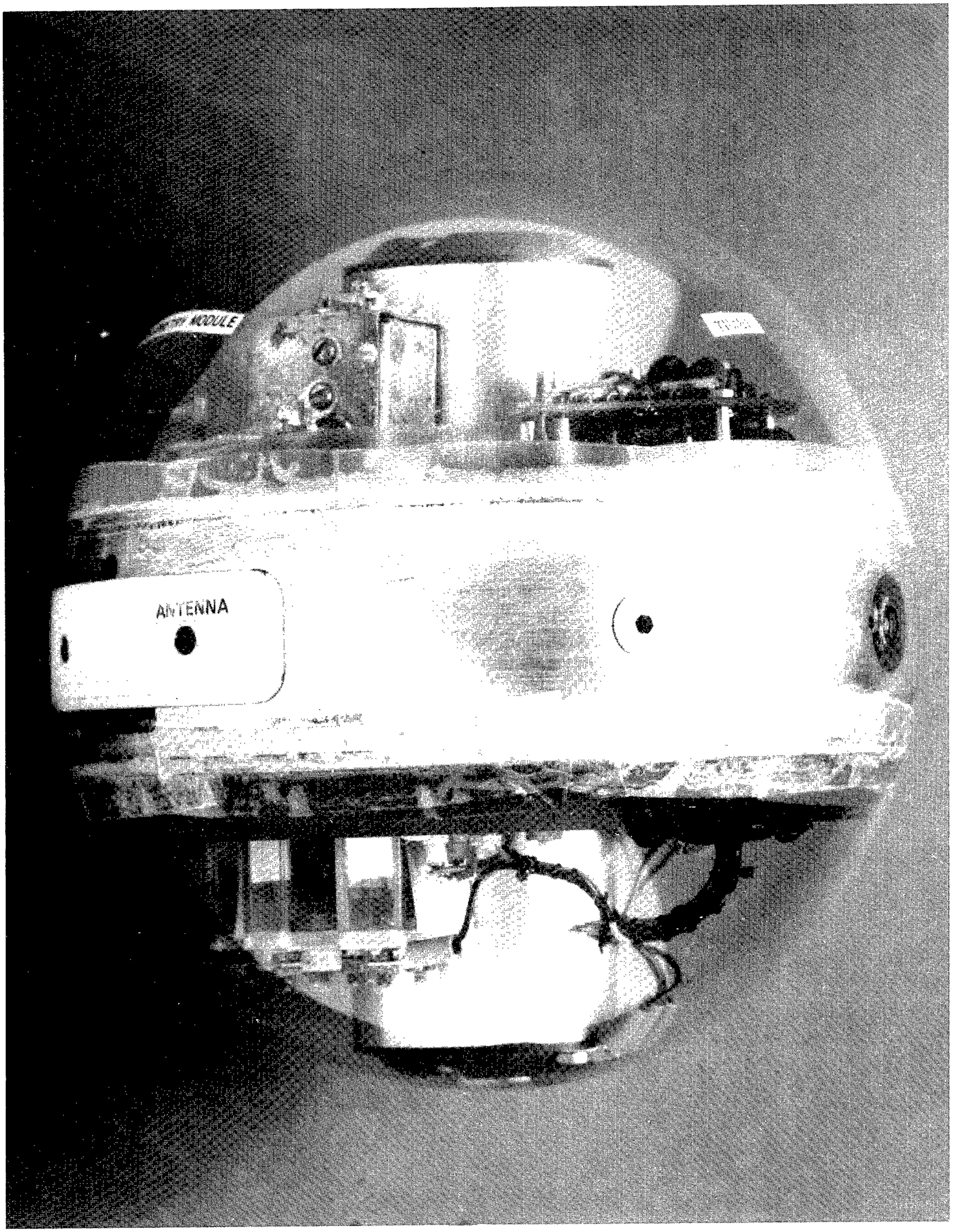

Figure 1. A Mock-up of a 7-inch Falling Sphere. The flight sphere had the top and bottom enclosed by aluminum hemispheres.

auroral optical emissions. Because of extremely high solar activity, intense particle precipitation and the high geomagnetic latitude of Churchill there were extensive auroras. They were whitish-green and appeared to be floating in diffused streaks which were continually changing.

3. PROJECT FIREFLY, EGLIN AFB, SUMMER 1960

In early summer 1960 a group of 30 or more scientists, engineers and technicians plus their families converged on Eglin AFB, Florida. N.W. (Bob) Rosenberg was project scientist and John Paulson, Bob Huffman , and I were part of the team. There were many contractors, including personnel from Georgia Tech, University of Georgia and GCA (formerly Geophysics Corporation of America). Ken Vickery was the Eglin Coordinator. We had about 30 rockets of the Nike Cajun type. Bob Rosenberg was a chemist, and many payloads were made while we were in the field. All the experiments involved release of material into the upper atmosphere and all required optical observations from two or more groundsites located at significant distances apart in Florida, Alabama, and Georgia. Because of the requirement for optical observations all rocket firings were made at night or at morning or evening twilight and all required either absence of clouds or significant breaks in them. Because of summer clouds from the Gulf of Mexico, the latter requirement often resulted in postponements or delays in rocket firings.

Some of the materials released were NO, Na, Ba, Cs, High Explosive, TMA (TriMethyl Aluminum) and small inert particles. Na and TMA made good visible trails, Ba and Cs, when sunlit, produced two distinct trails - one of neutral atoms and one of ions resulting from solar photoionization. In this case the neutral atom and ion clouds drift in different directions. The motion of the neutral cloud is determined by the atmospheric wind, but in the E (or F region) the direction of the earth's magnetic field is involved in determining the direction of drift of the ion cloud. The small inert particles (~ 1 micron in size) produced a little scatter at twilight. Ed Manring (GCA) and I did a calculation based on Mie scattering and this agreed with the observations. There were several other Firefly

field programs and AFCRL built up an international reputation for being the world leaders in upper atmosphere chemical release studies. The French sent personnel (Jacques Blamont and Marie Lise Chanin) to spend time with us in the field so they could learn our techniques.

4. NUCLEAR TEST SERIES - FISHBOWL SERIES 1962

This test series was developed and implemented in great haste in response to the Soviet Union's atmospheric and high altitude tests of very high yield devices. The Fishbowl Series was initiated in the Central Pacific in the summer of 1962. Measurements of the effects of the tests were made with instrumented rockets (the largest number ever used in a campaign), aircraft (including the AFCRL optical aircraft), ground based ionospheric radars, and optical cameras and spectrometers.

I was in charge of the AFCRL rocket experiments on Johnston Island and was also Safety Officer for the bunker that included all the key Air Force (AFCRL, AFWL), Army (BRL) and contractor personnel. I fired the first rocket of the group in each test series and usually also the last. Figures 2 and 3 contain photos respectively of me and A. Faire standing near Nike rockets. All the nuclear devices worked as planned but that was not true of all the rockets. This resulted in some tests being repeated. One of the high altitude tests resulted in the sky being lit up over Honolulu.

The Starad satellite was launched on 26 Oct 62. Ludwig (Lou) Katz measured trapped particle radiation injected by Starfish until 18 Jan 63. Jim Ulwick measured electron densities on the same satellite. Additional measurements were made with other satellites.

5. OTHER ROCKET PROGRAMS

An important project was to develop rocket instruments to measure atmospheric density at higher altitudes (above about 100 km) than is possible with the rocket-borne 7-

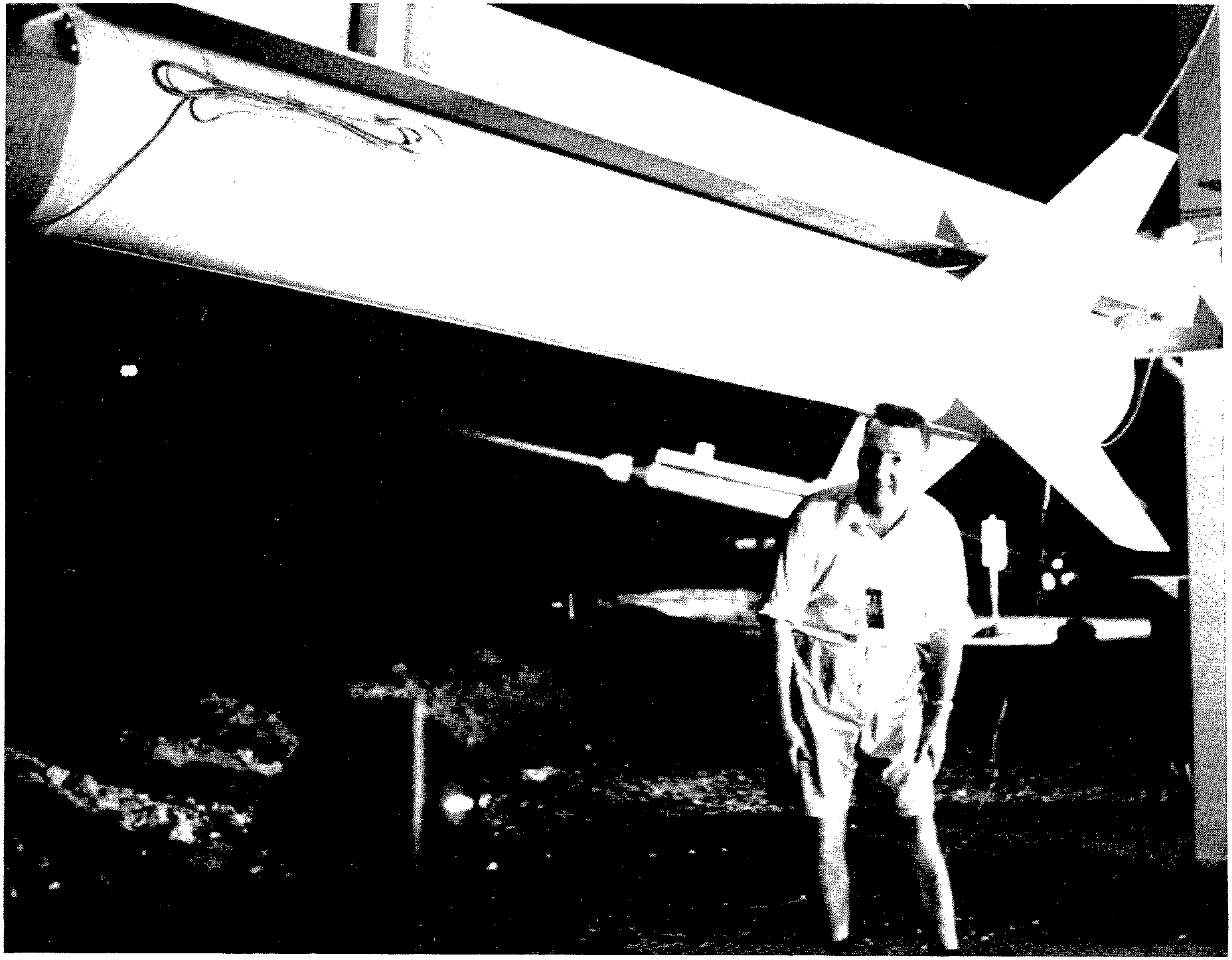

Figure 2. The Author Standing Under a Nike Rocket on a Launch Rail.

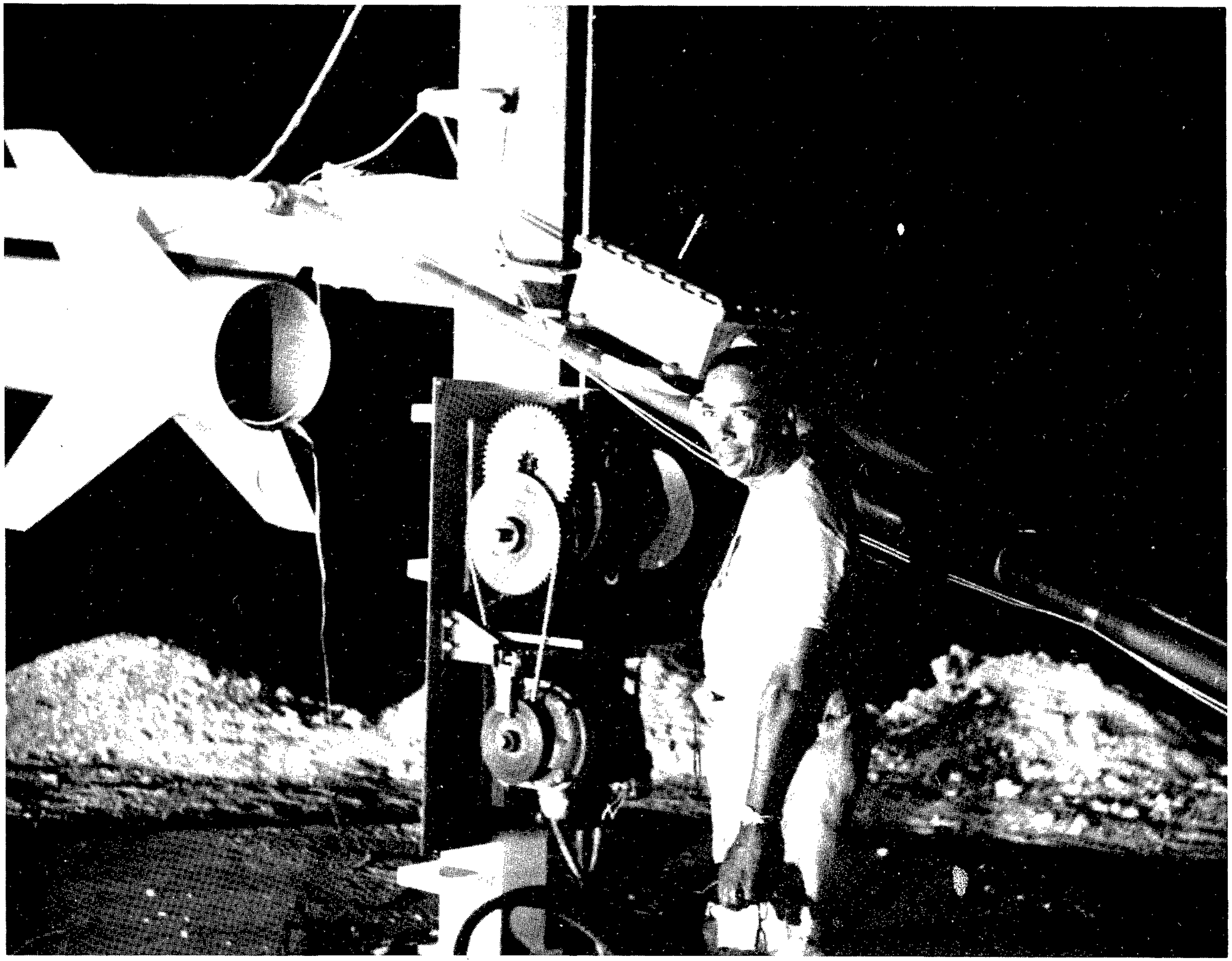

Figure 3. Andy Faire Standing Beside a Launch Rail Showing the Raising Mechanism.

inch falling sphere. The reason is that the properties of this region (primarily 100 to 150 km) are not accurately known and thus this region is often called the "Ignorosphere". It is important for developing accurate models of the neutral atmosphere and ionosphere and for many applications, such as predicting the reentry of satellites. The following rocket techniques were developed to help fill in this lack of data and a number of measurements were made providing useful information.

5.1 Ten Inch Falling Sphere.

This contains a triaxial piezoelectric accelerometer and provides the drag acceleration components in three mutually perpendicular directions. From these data the drag due to atmospheric density and due to wind (if strong enough) can be derived. Figure 4 shows the electronics and end of the accelerometer. Figure 5 shows the complete sphere being mounted on the payload assembly. This instrumented sphere is more sensitive than the 7-inch sphere and thus can measure density to higher altitudes. C.R. (Russ) Philbrick was the program scientist.

5.2 Inflatable Sphere.

This sphere inflates when ejected from a rocket at altitude. It is approximately 1.5 meters diameter, and contains an accelerometer, gas under pressure, timer, and control and telemetry systems. Because of its lower mass to area ratio it can measure drag and, hence, density to higher altitudes than the 7-inch sphere. Figure 6 shows Jerry Faucher and Roland Matson looking at an inflated sphere.

5.3 Bremsstrahlung.

An electron beam is emitted from a rocket and the back-scattered bremsstrahlung can be used to determine the atmospheric density.

5.4 Rayleigh scatter.

This is a similar technique but uses a flashing light or laser as the radiation source and the backscattered Rayleigh scatter is used to measure atmospheric density.

5.5 O_2 Density profiles.

Figure 7 contains plots of O_2 density data obtained by several scientists during the period 1955-1965. Most of the measurements were made using the technique of solar ultraviolet

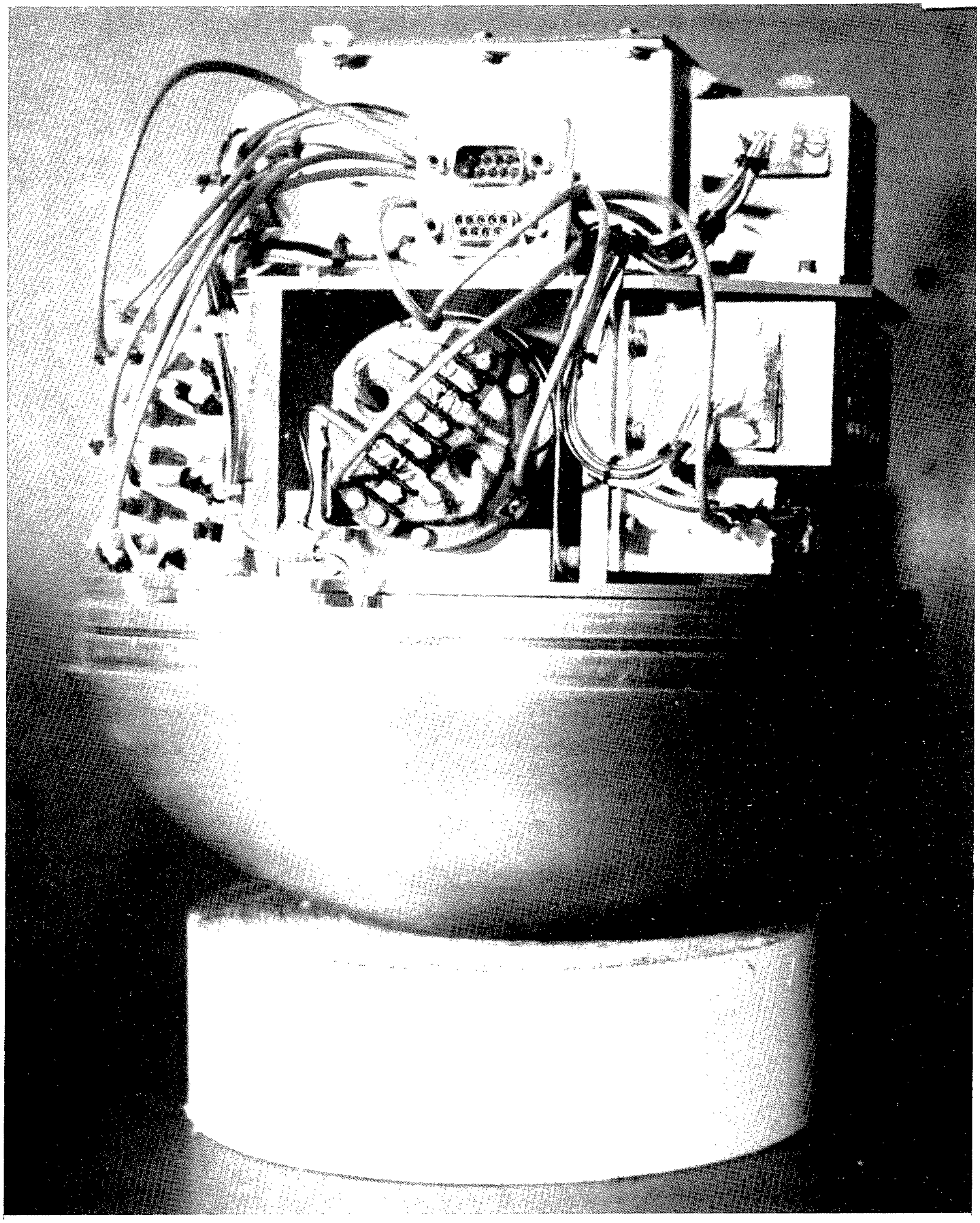

Figure 4. The Inside of a 10-inch Falling Sphere Showing the Electronics Boxes and the End of the Cylinder Containing the Triaxial Piezoelectric Accelerometer.

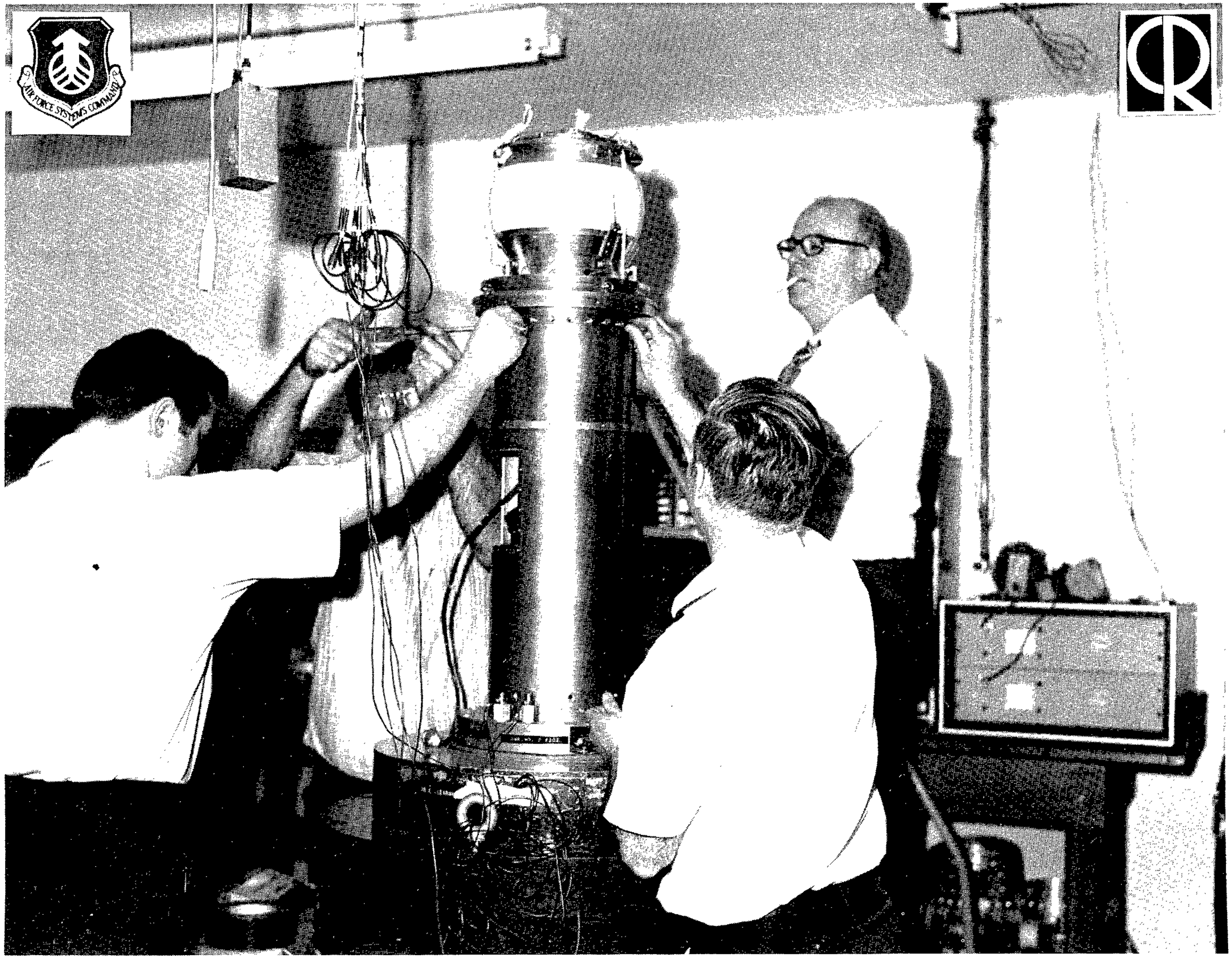

Figure 5. A Complete 10-inch Sphere Being Mounted on the Payload Assembly. The antennas are mounted inside the equatorial band.

Figure 6. A 1.5 meter Diameter Inflatable Sphere. The central cylinder contains an accelometer, telemetry system and all the electronics required to operate the sphere systems.

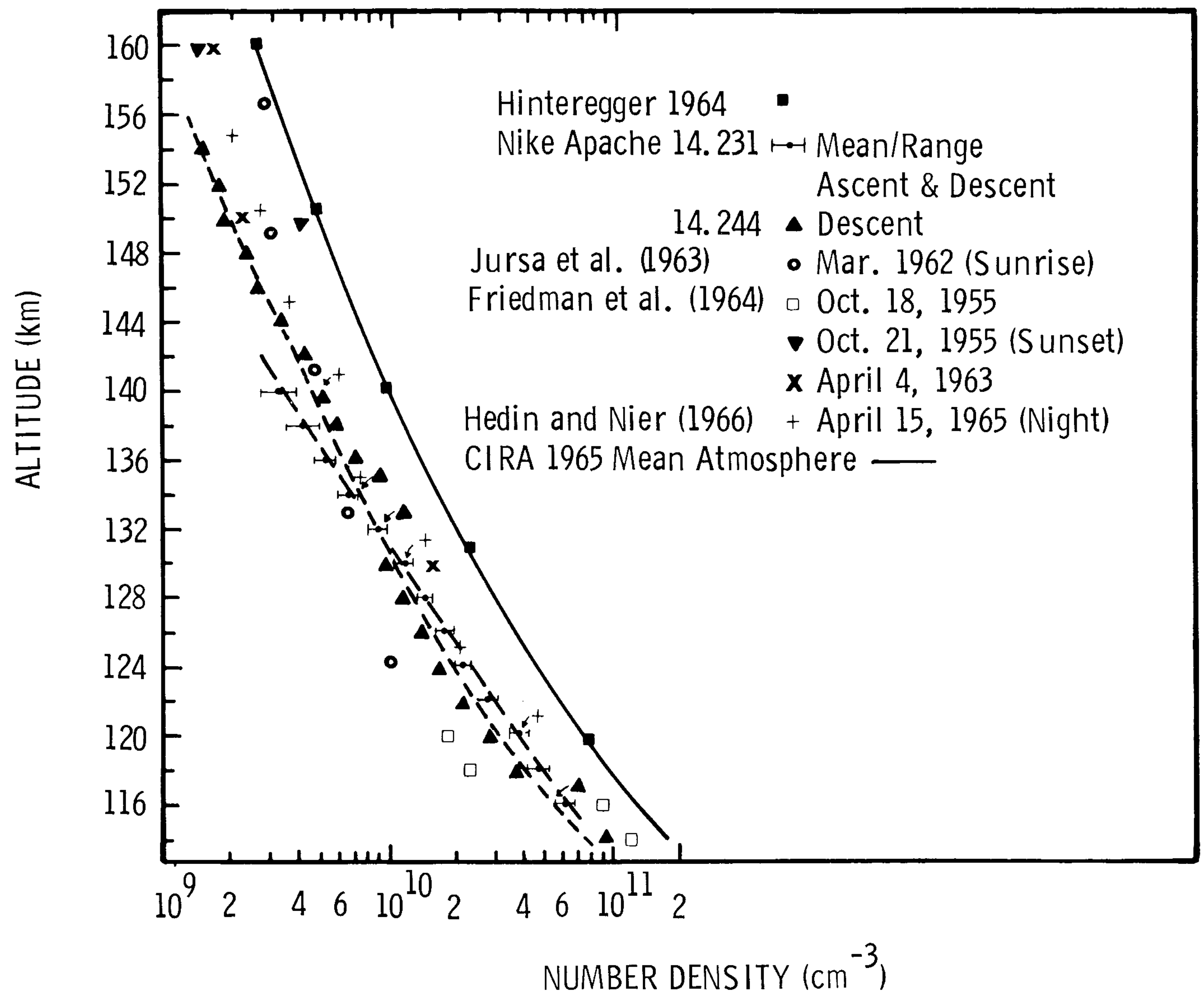

Figure 7. Early Rocket Measurements of O_2 Density Profiles. Most of the measurements were made using the technique of solar ultraviolet absorption. The measurement of Hedin and Nier was made with a mass spectrometer.

absorption. The measurement of Hedin and Nier on April 15, 1965 was made with a mass spectrometer. In comparing the absolute magnitudes of the O_2 density it is necessary to take into account the natural variations with solar activity and time of day. An important point is the contributions of AFCRL to this research as represented by Jursa et al, March 1962[3] and Hinteregger 1964[4].

6. MAJOR FIELD PROGRAMS.

We were involved in many other major rocket field programs, but the largest and most important was Operation PCA 69*. This was a coordinated rocket, satellite, aircraft and ground measurement program designed to study the physics and chemistry of the ionosphere D-region during and after a solar proton event. These events provide a good simulation of the effects of high altitude nuclear detonations and major support for this program was provided by DASA (Defense Atomic Support Agency). Jim Ulwick was the program manager.

Coordinated measurements were made starting on 2 November 1969. A total of 36 rockets were fired at Fort Churchill, Canada during a two-day period to make measurements of various atmospheric properties with emphasis on temporal variations, particularly at sunrise and sunset. Electron and proton flux measurements were made on several satellites, optical aircraft measurements were made and so were ground based riometer, magnetometer, ionosonde and partial reflection measurements.

Figure 8 shows the absorption levels for the 30MHz riometer at Churchill during the event from 2 to 4 November 1969. The levels of absorption are relative to an average quiet day. The solar zenith angle is also shown. An indication of when each rocket was fired is at the top of the figure. The sphere NIRO is the notation for rockets launched to measure neutral density and temperature, while the POS.NIRO and NEG.NIRO refer to rockets carrying positive and negative ion mass spectrometers respectively. The program was very successful and the results were presented at a

*PCA denotes Polar Cap Absorption (Event)

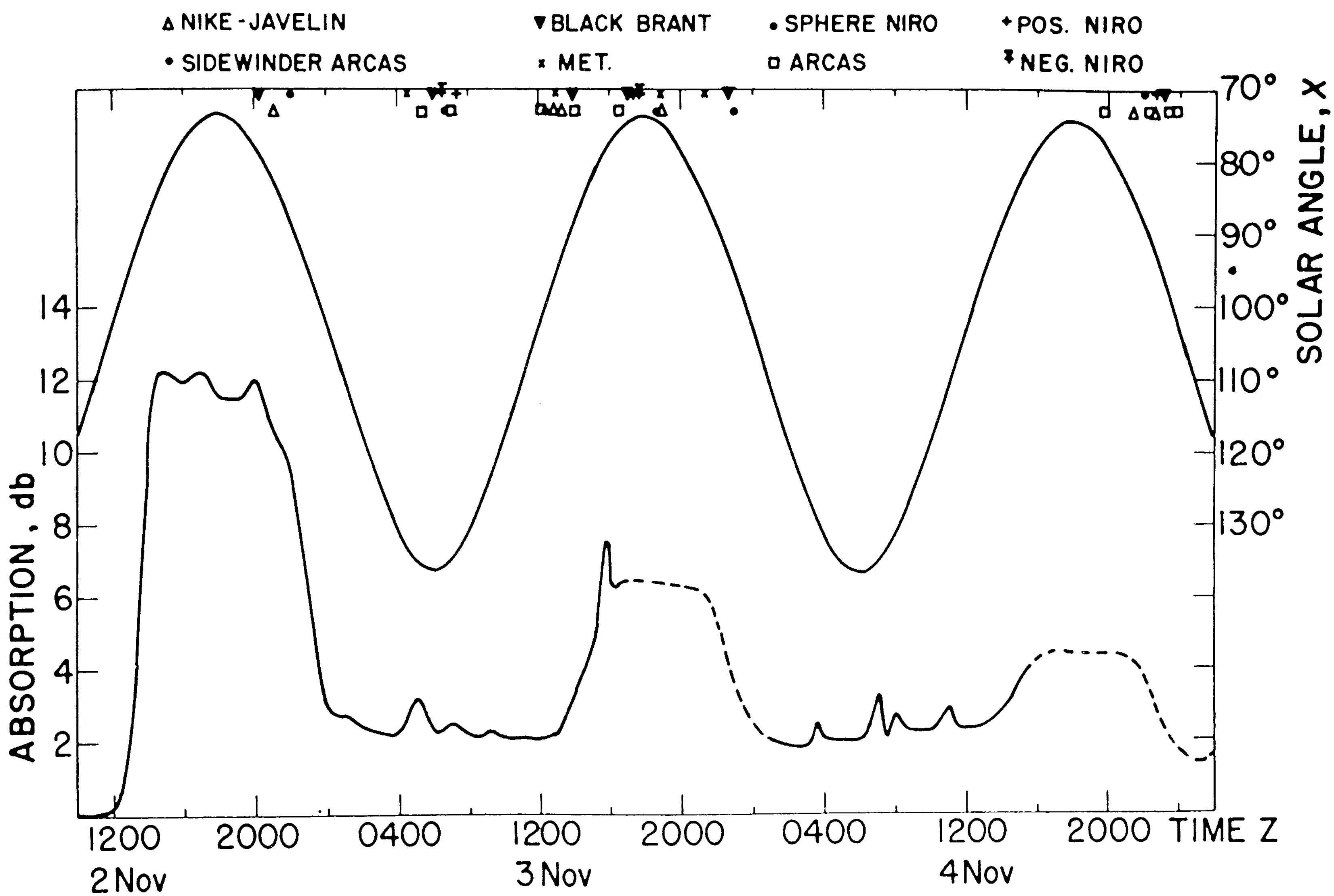

Figure 8. Solar Zenith Angle and 30 MHz Polar Riometer Absorption Levels at Churchill during the period 2 to 4 November 1969. The dashed lines indicate uncertain data. The high energy proton flux (>25 Mev) reached maximum (10^3 counts/sec) soon after 1200 on 2 November but decayed to 30 counts/sec 24 hours later.

Conference at Boston College, Massachusetts[5] on 31 March and 1 April 1970.

We were also involved in a number of Eclipse Expeditions to various locations in conjunction with the Army Ballistic Research Laboratories represented by Warren Berning.

7. SATURN V TEST

As part of the Apollo Lunar Program it was necessary to flight test the new Saturn V rocket. It was desirable to do the test without the upper stages and the lunar landing module attached to it. Thus it was proposed to use 100 tons of water as ballast. It was also proposed to release the water into the atmosphere at an altitude of about 100 km, partly because it was not desirable for the Saturn V to land carrying this amount of ballast. NASA asked the National Academy of Science (NAS) to set up a Committee to review the expected impact of such a release on the upper atmosphere and ionosphere. The Committee was chaired by Will Kellogg and I was a member. The Committee predicted that the released water would produce a moderately big hole in the lower E region within which the electron density would be significantly reduced and that it would drift due to atmospheric winds. They also predicted that the effect would last for about two hours. The Saturn V flight test was performed and the effects of the water release were exactly what we had predicted.

8. DNA REACTION RATE PROGRAM

A tremendously successful and long-lived research program was the DASA/DNA* Reaction Rate Program, which started in 1960 and terminated in 1983, at which time <u>its goals had been far exceeded.</u> Most of the top reaction rate scientists in the country were involved. They included physicists, chemists, experimenters and theoreticians. The scientists included Lew Branscomb, Fred Kaufman, Fred Biondi, Art Phelps, Eldon Ferguson, Harvey Michaels and many others, including John Paulson and Ed Murad from AFCRL. I was the Project Manager.

After the first conference in what is now the NOAA facilities at Boulder there was an evening committee meeting. At that meeting Lt Col Bill McCormac (the Chief DASA representative) said that he wanted us to specify before the end of our meeting the ten most important reaction rates that had to be obtained so that the ionization produced in the D and E regions by nuclear detonations could be determined. The reaction of the group of senior scientists to this request was as would be expected. Actually it was even more impossible than we realized at the time. At that time little was known about the basic phenomena (aeronomy) of the D and E regions. In addition, little was known about cluster ions, primarily with water $(H_2O)_n$. X, heterogeneous reactions with aerosols and negative ions in the D region, and ions like Fe^+, Ca^+, Mg^+, primarily from vaporization of meteorites, in the E-region.

Nevertheless, with a combination of laboratory measurements, modeling, and interaction with the results of field measurements, including some of Rocco Narcisi's work, most of the problems were solved after 23 years. There are still some uncertainties with the rates of heterogeneous (surface) reactions and measurements of aerosols in the atmosphere. For many years Charles Blank was the Program Manager at DNA and for more than 10 years I organized a Reaction Rate Conference, the abstracts for which were published by AFCRL.

*DASA stands for the Defense Atomic Support Agency whose name was changed to DNA, the Defense Nuclear Agency

9. SATELLITES AND MODEL ATMOSPHERES.

9.1 Satellite Orbits and Atmospheric Density

The first artificial satellite (Sputnik) was placed in orbit by the Soviet Union in October 1957. Very soon after that Project Harvest Moon was initiated at AFCRL. It was housed in a large room in Building 1102F at Hanscom AFB. Bob Slavin from the Rocket and Balloon Division was in charge of the Project. They obtained tracking observations from

radars and the Smithsonian Observatory's Baker Nunn cameras. The latter instruments provided very accurate position location for satellites, as their images could be seen against a background of known stars whose positions were known very precisely. Soon there were several U.S. and Soviet satellites in orbit. Project Harvest Moon personnel calculated orbits of the satellites from the observations. They gave me the orbital elements and from their rate of change with time I calculated atmospheric drag effects and from these the atmospheric densities.

Figure 9 contains a reproduction of a handdrawn plot of mine showing the latitudes of the early satellites as a function of time. The Soviet Sputniks had an orbital inclination of about 60° due to the high latitude of their launch site. The Explorer and

Vanguard satellites had an orbital inclination of about 34° due to a low latitude launch site. Note that Explorer IV had an orbital inclination of 50° in an attempt to provide global coverage approaching that of the Sputniks. The Sputnik satellites were relatively low in altitude and thus had relatively short life times, as can be seen in Figure 9. Note also that it appears that the launch of Explorer II was not successful.

9.2 ARDC 1959 Model Atmosphere

In 1958 Ray Minzner and I gave a joint seminar at Harvard Observatory. Ray talked about the 7-inch falling sphere measurements and I talked about the upper atmosphere densities I had calculated from the satellite data. Soon thereafter, we put together the available rocket and satellite data[6] and developed a mean model atmosphere that was published as the ARDC* 1959 Model Atmosphere[7]. This was the first official atmosphere in the world to include satellite density data and it was significantly different from the previous Standard Atmospheres. It was at that time that the Smithsonian observatory arranged for Marcel Nicolet to spend a summer with them to develop a set of thermospheric models as a function of the exospheric temperature. Later Luigi Jacchia took these models and determined parameters to link the exospheric temperature, and thus

*ARDC - Air Research and Development Command.

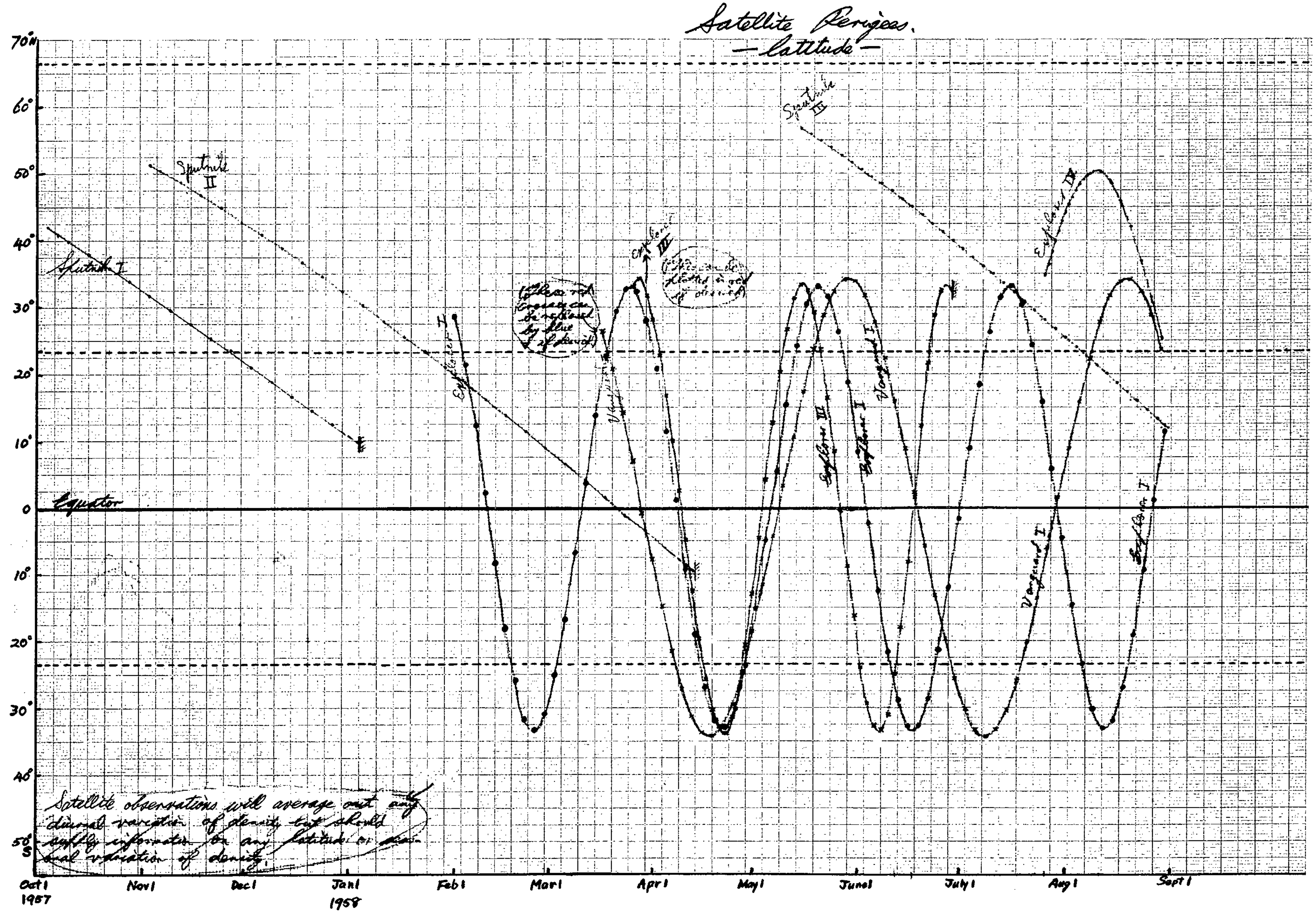

Figure 9. Plot of the Perigee Latitudes of the First Satellites From Their Launch until the End of August 1958 or Their Reentry. The Sputniks had an orbital inclination of about 60° and the Explorer and Vanguard satellite about 34° due to the latitudes of their respective launch sites.

atmospheric density profiles, to latitude, time of day and solar activity.

As the number of satellites in orbit rapidly increased, Project Harvest Moon was converted to Space Track, an operational organization, and was moved to a new building at Hanscom AFB. In time a facility for Space Track was developed inside Cheyenne Mountain, Colorado, for greater physical security, and it was moved there. The facility at Hanscom continued to be operated for some time as a backup to Cheyenne Mountain but was then terminated.

9.3 U. S. Standard Atmosphere, 1962

Following publication of the ARDC 1959 Model Atmosphere we were involved in the development of a whole succession of Standard and Reference Atmospheres. One of the organizations in which we were involved was COESA. It was the U.S. Committee for the Extension to the Standard Atmosphere. The basic standard atmosphere is the one produced by ICAO* which is used for the design and operation of all aircraft, and consequently only exists for relatively low altitudes (originally 0 to 20 km).

COESA was sponsored by NASA, USAF (representing the DoD) and USWB (the U.S. Weather Bureau and its successor organizations) and included representatives of about 30 scientific and engineering organizations, each holding national responsibilities for accurate models and data of the lower and upper atmosphere. Some of the contributors to Standard Atmospheres are shown in Figure 10. COESA's first report was the "U.S. Extension to the ICAO Standard Atmosphere - Tables and Data to 300 Standard Geopotential Kilometers, 1958.[8] This report was quickly rendered obsolete by satellite data which gave densities at upper altitudes which were more than an order of magnitude different from those given in the report. Thus in January 1960 COESA set up four Task Groups to develop a completely new Standard Atmosphere. The revised atmosphere to 700 km[9,10] was adopted by COESA as the U.S. Standard Atmosphere, 1962[11] on March 15, 1962. Figure 11 shows a comparison, at altitudes between 80 and 300 km, of

---

*ICAO - International Civil Aviation Organization

Figure 10. An Early Meeting of Contributors to Standard Atmospheres. Front Row: S. Fritz, N. Sissenwine, B. Haurwitz, F. Whipple, K. Champion, L. Jacchia, W. Kellogg. Back Row includes: H. Pond, D. Johnson, C. Stergis.

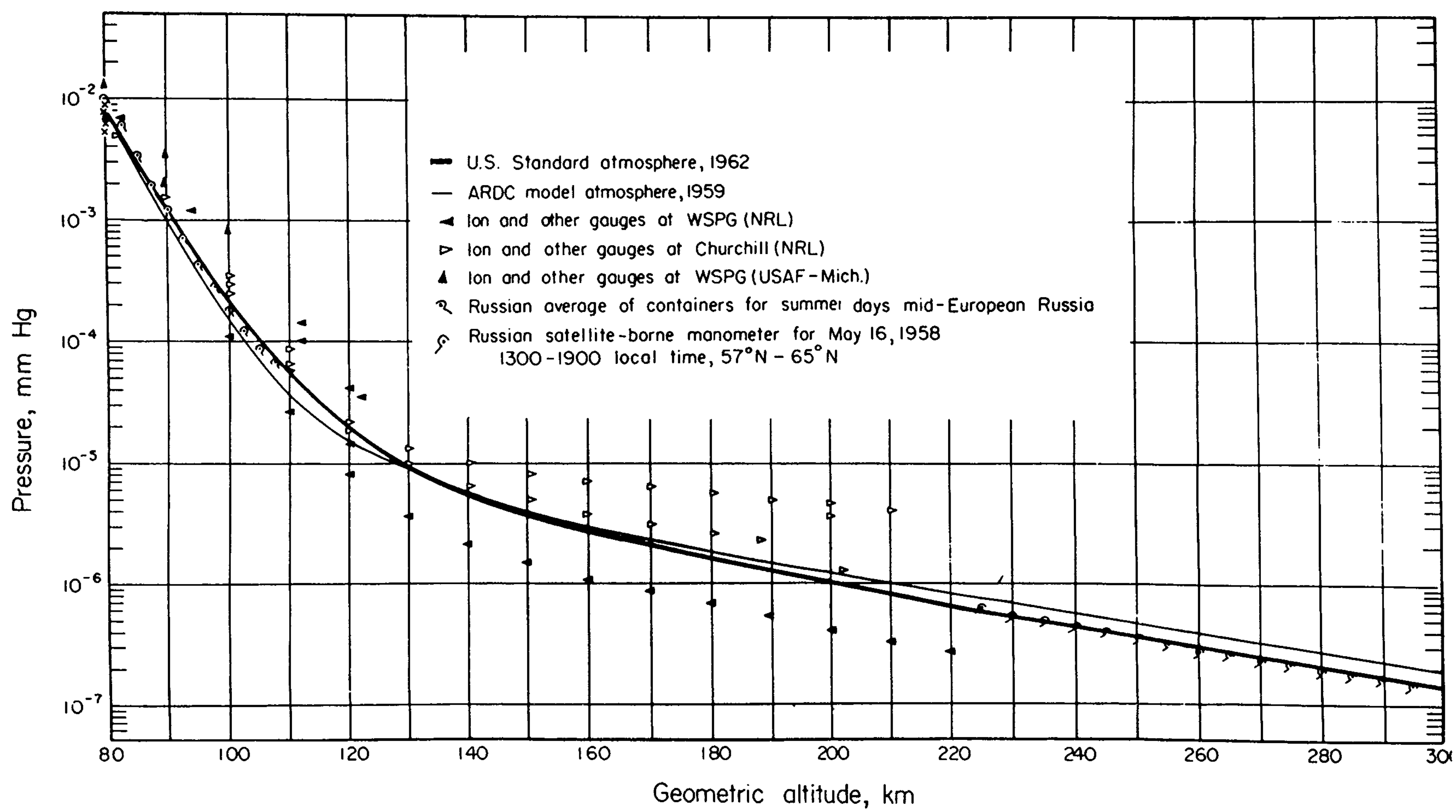

Figure 11. Pressures of U.S. Standard Atmosphere 1962, the ARDC Model Atmosphere 1959 and Data From Rockets and Satellites. The wide data spread is largely instrumental, but is also partly due to atmospheric variability.

pressures given by the U.S. Standard 1962, the ARDC Model Atmosphere 1959 and data from rockets and satellites. The data variability is partly due to atmospheric variability and partly due to instrumentation effects.

9.4 U. S. Standard Atmosphere Supplements, 1966

Standard Atmospheres provide a mean set of atmospheric properties: for example the U.S. Standard Atmosphere provides mean values for 45^0 N latitude for all times of day, year, and solar activity, but for many purposes including the design and operation of aerospace vehicles it is necessary to have information on the range of variability of the atmosphere. Thus COESA developed the U.S. Standard Atmosphere Supplements, 1966[12] The COESA Working Group met at Fort Collins, in July 1963 and at the University of Miami in January 1965 to steer the development. Most of the development of the models included in the publication was done by Alan Cole and Arthur Kantor (0 to 80 km), merging models (80 to 120 km) by me[13] and above 120 km by Jacchia. Figure 12 shows contours of density departures from the 1962 Standard for a representative set of conditions.

9.5 U. S. Standard Atmosphere, 1976

Due to extensive new rocket and satellite data and improved models of the mesosphere and thermosphere since the publication of the U.S. Standard Atmosphere, 1962 it was decided at a meeting of the COESA Working Group in September 1971 to initiate work to develop an updated standard. To achieve this goal, five task groups were established. These were Task Group I (50 to 100 km) A. Cole, Convener, Task Group II (80 to 200 km) R. Minzner[14] Convener, Task Group III (140 to 1000 km) L. Jacchia, Convener, Task Group IV (Unification of 50 to 1000 km) of which I was the Convener, and Task Group V (minor constituents and particulates up to the mesopause) R. Cadle, Convener. Note that it was not proposed to revise the U.S. Standard 1962 between 0 and 50 km because it had been adopted by ISO (International Standards Organization) as its standard in September 1973 and was under consideration for adoption by ICAO.

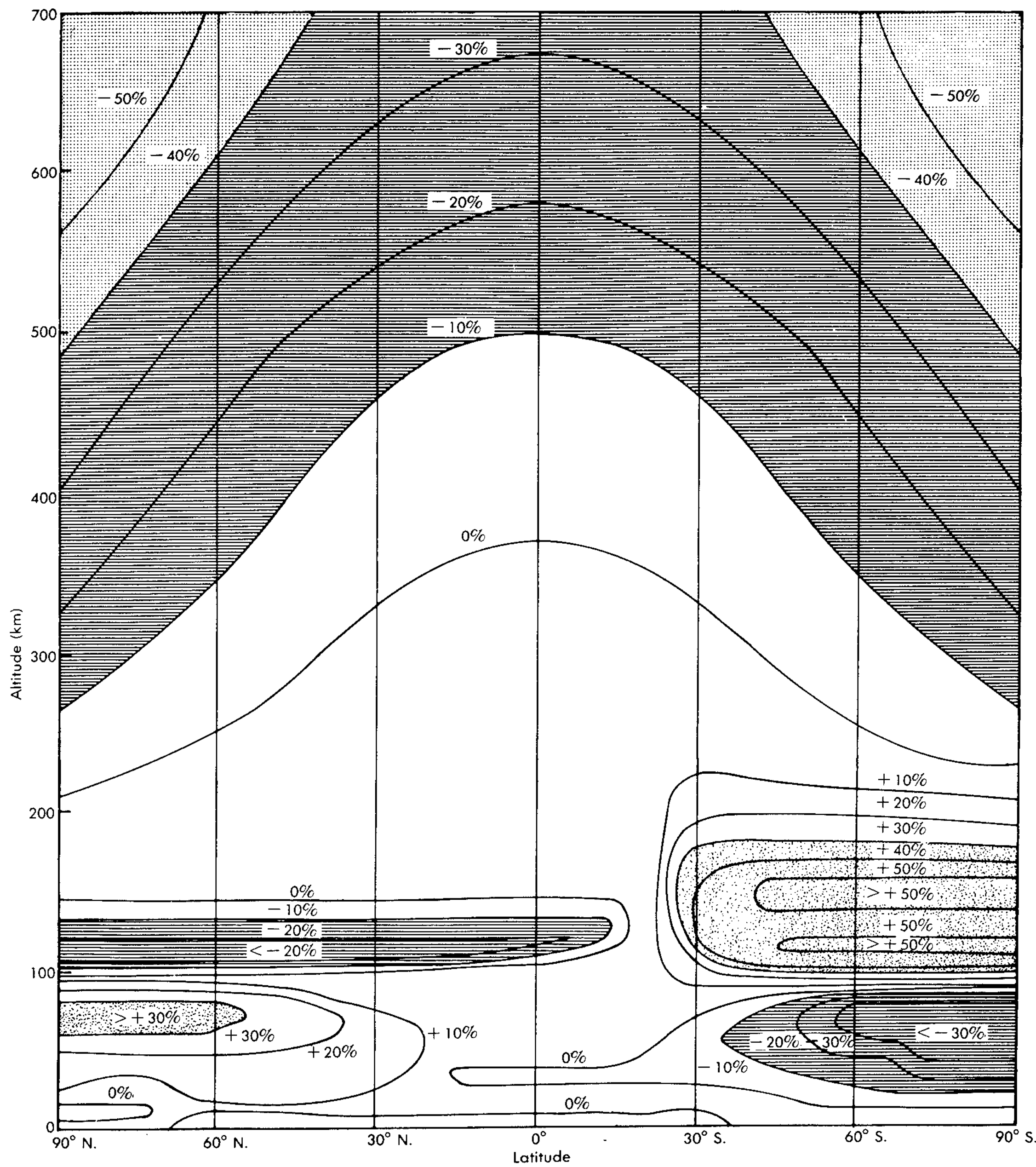

Figure 12. Contours of Percent Departures of U.S. Standard Atmosphere Supplements 1966 Density Values From the 1962 Standard Values for 1400 hours Local Time at Northern Hemisphere Summer Solstice and a Maximum Exospheric Temperature of 1200K.

Task Group I analyzed temperature data derived from grenade, pitot-static tube, and falling sphere measurements at eight rocket-launch sites at latitudes from 6^0 to 71^0. Smooth curves were drawn through the data at specified altitudes and interpolated values at 45^0 N were derived. These values provided the basis for the temperature profile for the new Standard except between 85 and 90 km where it was lowered by approximately 3 degrees to provide a better match with the lower thermosphere data.

For altitudes above 140 km many data exist from satellite and incoherent radar scatter measurements, but for altitudes between 90 and 140 km there are data from only a limited number of measurements. Thus comprehensive models are made for the thermosphere and the best possible match is made in the lower thermosphere with the lower altitude models. The models were published as the U. S. Standard Atmosphere, 1976.[15]

Useful information is provided in the new Standard on 11 minor molecular constituents, in addition to water vapor and aerosol content.

10. COSPAR

COSPAR (Committee on Space Research) is a Committee of ICSU (the International Council of Scientific Unions) responsible for disseminating and enhancing the scientific results and understanding of space by means of measurement by instruments on balloons, rockets and satellites, and related theories and models. Scientists from AFCRL have played important roles in the activities of COSPAR since its first scientific meeting in Nice, France in 1960. AFCRL personnel have presented many papers, been members of committees, chaired sessions, and edited publications. Hans Hinteregger with his measurements of solar ultraviolet radiation was an early participant in its meetings. Since 1962 I have been a member or officer of many committees, panels, and working groups, including Chairman of Interdisciplinary Scientific Commission C. The disciplines covered by this Commission included studies of the upper atmospheres and ionospheres of the earth and planets, and reference atmospheres.

11. COSPAR INTERNATIONAL REFERENCE ATMOSPHERES

11.1 CIRA 1961 AND CIRA 1965

The first COSPAR International Reference Atmosphere (CIRA) appeared in 1961 and was based primarily on data obtained during years of very high solar activity (1958-1960). It was soon realized that the models would not represent the upper atmosphere during periods of reduced solar activity. Thus COSPAR Working Group IV on the International Reference Atmosphere was set up under the chairmanship of Wolfgang Priester. At the COSPAR meeting in Warsaw in June 1963 it was decided to develop a new set of models. These were completed and published two years later as CIRA 1965[16]. It consists of three parts; (1) a mean atmosphere from 30 to 300 km, which I prepared, (2) tables of atmospheric structure and its variations in the region from 30 to 100 km compiled by G.V. Groves, and (3) tables of mid-latitude diurnal atmospheric variations in the region 120 to 800 km, prepared by I. Harris and W. Priester.

11.2 CIRA 1972

One major limitation of the CIRA 1965 thermospheric models was that they were given for only one latitude and solar declination. For many purposes, including computations of satellite orbits, atmospheric variations with latitude are very important. Thus at the COSPAR meeting in Prague in 1969 it was decided to develop a third edition of CIRA under the direction of G.V. Groves, L. G. Jacchia, and myself. At the COSPAR meeting in Leningrad in 1970 the Working Groups were reorganized and Jacchia was named Chairman of a new COSPAR Working Group 4 on Experiments in the Upper Atmosphere, and M.Y. Marov and I were appointed Co-Chairmen of Panel 4A on the Structure of the Upper Atmosphere (including the Committee for CIRA). The revised reference atmospheres were published as CIRA 1972[17]. This, like CIRA 1965, consisted of three principal parts; (1) The mean COSPAR International Reference Atmosphere (25 to 500 km) prepared by R.A. Schweinfurth, and myself, (2) Atmospheric Structure and its

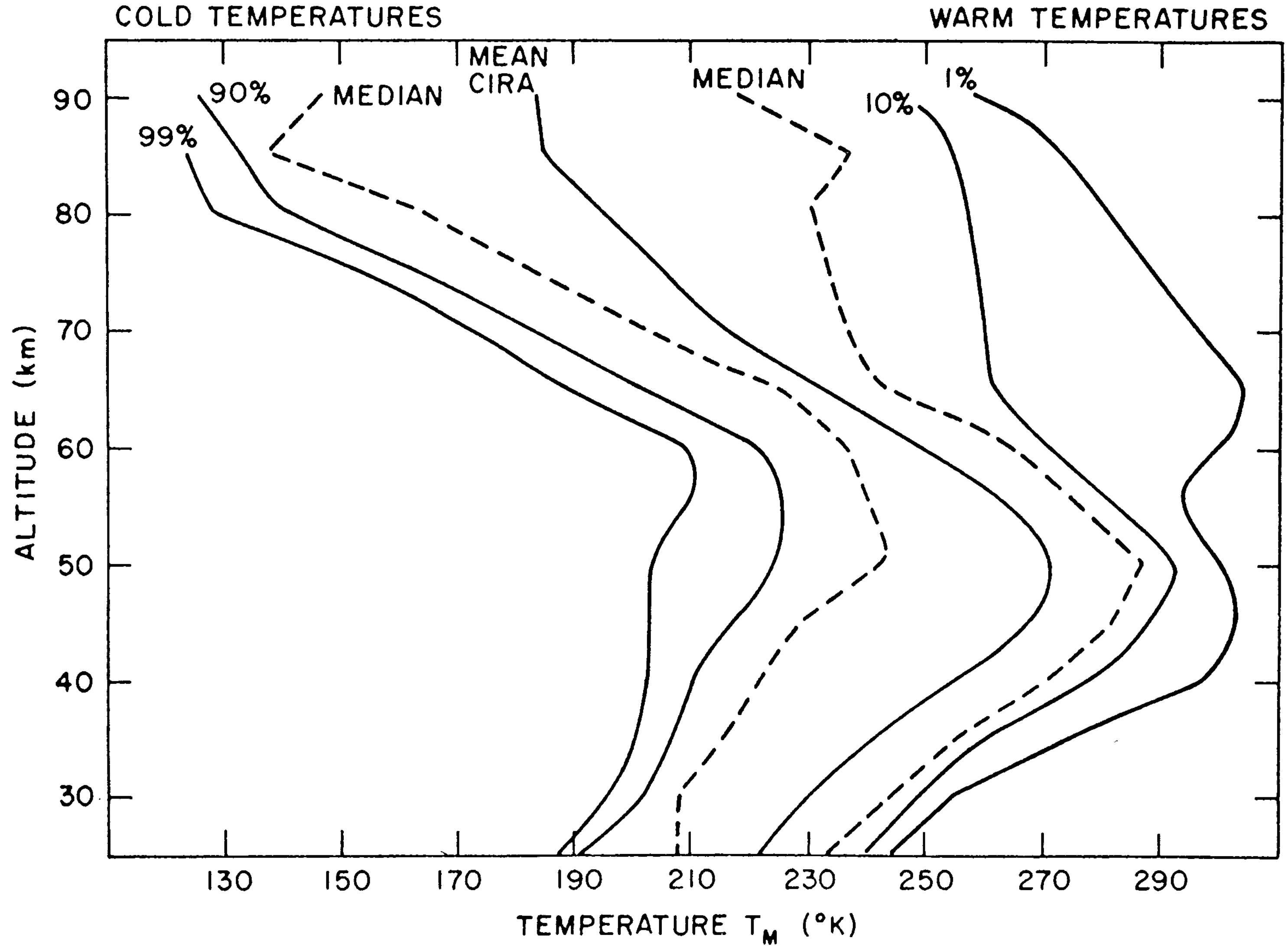

Figure 13. Variability of Atmospheric Temperature Between 25 and 90 km in Percentile Departures From the Mean CIRA 1972 Temperature Profile.

Variations in the Region from 25 to 110 km, prepared by G.V. Groves, and (3) Atmospheric Models in the Region from 110 to 2000 km, prepared by L.G. Jacchia. Figure 13 is from part (1) of CIRA 1972 and depicts the variability of atmospheric temperature between 25 and 90 km in percentile departures from the mean CIRA temperature profile.

11.3 CIRA 1986

Since 1972 there has been a big increase in data from satellites; in particular, remote soundings of the middle atmosphere have provided global coverage of that region. In addition, data from ground-based MST (mesosphere, stratosphere and troposphere) radars and from meteor and incoherent scatter radar measurements of temperature and winds have made major contributions at a number of locations. Routine analyses of radiosonde measurements of pressure and temperature have also become available for the lower stratosphere in both hemispheres. These new data were used in deriving the new middle atmosphere CIRA 1986, Part II.[19] J. J. Barnett, K. Labitzke, and D. Rees were major contributors to this effort and I was Chairman of COSPAR Commission C under whose direction the new CIRA was developed.

A number of updated empirical models of the thermosphere have been developed since CIRA 1972 was published. The comprehensive models prepared by A. Hedin were chosen for inclusion in CIRA 1986, Part I.[18] They were based on the Mass Spectrometer/Incoherent Scatter (MSIS) 1986 models. There has also been major progress in the development of theoretical Thermospheric General Circulation Models (TGCMs) by D. Rees et al and by R. G. Roble and colleagues. The models developed by Rees and Fuller-Rowell are presented in CIRA 1986. Part I also contains five chapters reviewing contributions to our understanding of the thermosphere from several different types of experimental data. For the first time computer programs are available for reproduction of either the empirical or theoretical models.

12. IRI

Another important COSPAR product in which AFGL personnel have been involved included the development of the International Reference Ionosphere (IRI) which is sponsored both by COSPAR and by URSI (International Union of Radio Science). In 1968 COSPAR adopted a proposal to develop an International Reference Ionosphere (IRI)[20] following the success of the CIRA project. Karl Rawer was selected to become the first chairman of the IRI Task Group. In 1969 URSI decided to cosponsor the project. COSPAR's interest was in a specification of the ionosphere, analogous to that done for the neutral atmosphere in CIRA. The interest of URSI was to provide a basis for long and medium term global radiowave propagation predictions.

Rawer brought together a distinguished team of experts representing the different ground and space measurement techniques and different scientists interested in ionospheric research. These included D. Bilitza and other personnel from his Institute, the Institut für Physikalische Weltraumforschung (Institute for Physical Space Research) in Freiburg, Germany. Members from the U.S.A. included D. Anderson and myself (AFCRL), and K. Bibl and B. Reinisch (U. Lowell). A first set of preliminary tables was presented at the 1972 URSI General Assembly. The first widely distributed edition was IRI 1978. This edition used the CCIR (Consultative Committee on International Radio propagation) world maps for the F2 peak parameters and was also available as ALGOL and FORTRAN computer codes. A revised version of IRI 78 was released as IRI 79, a report containing a large number of plots and tables and published by the World Data Center A for Solar Terrestrial Physics, Boulder, CO[21]. The latest edition, IRI 90, is based on the addition of considerable new data from satellites, rockets and ground-based measurements and is available as a report[22] or computer software.

13. INSTRUMENTS ON SATELLITES

13.1 Early Pressure Gauge Density Measurements

The Air Force Geophysics Laboratory has had instruments on many satellites

LAUNCH DATE	SATELLITE	SCIENTIST	EXPERIMENT
16 JUN 61	DISCOVERER 25	J. McISAAC	ATMOSPHERIC DENSITY GAUGE
3 APR 65	SNAPSHOT/SECOR 4	J. McISAAC	DENSITY GAUGES
5 DEC 67	OV3-6 (ATCOSII)	J. McISAAC	DENSITY GAUGES
11 JUL 68	OV1-15 (SPADES)	K. CHAMPION	ACCELEROMETER/ IONIZATION GAUGE/MASS SPECTROMETER ACCELEROMETER
	OV1-16 (CANNON-BALL 1)	R. PHILBRICK	
7 AUG 71	OV1-20 (CANNON-BALL II)	K. CHAMPION	LOW ALTITUDE DENSITY ACCELEROMETER
	OV1-21 (MUSKET-BALL)	K. CHAMPION	LOW ALTITUDE DENSITY RADAR BEACON
	DENPER	R. NARCISI R. PHILBRICK J. McISAAC	MASS SPECTROMETERS IONIZATION GAUGES

Figure 14. Some of the Early Satellites on which AFCRL had Experiments. The experiments included density gauges, accelerometers for measuring drag and density, and mass spectrometers for measuring atmospheric composition.

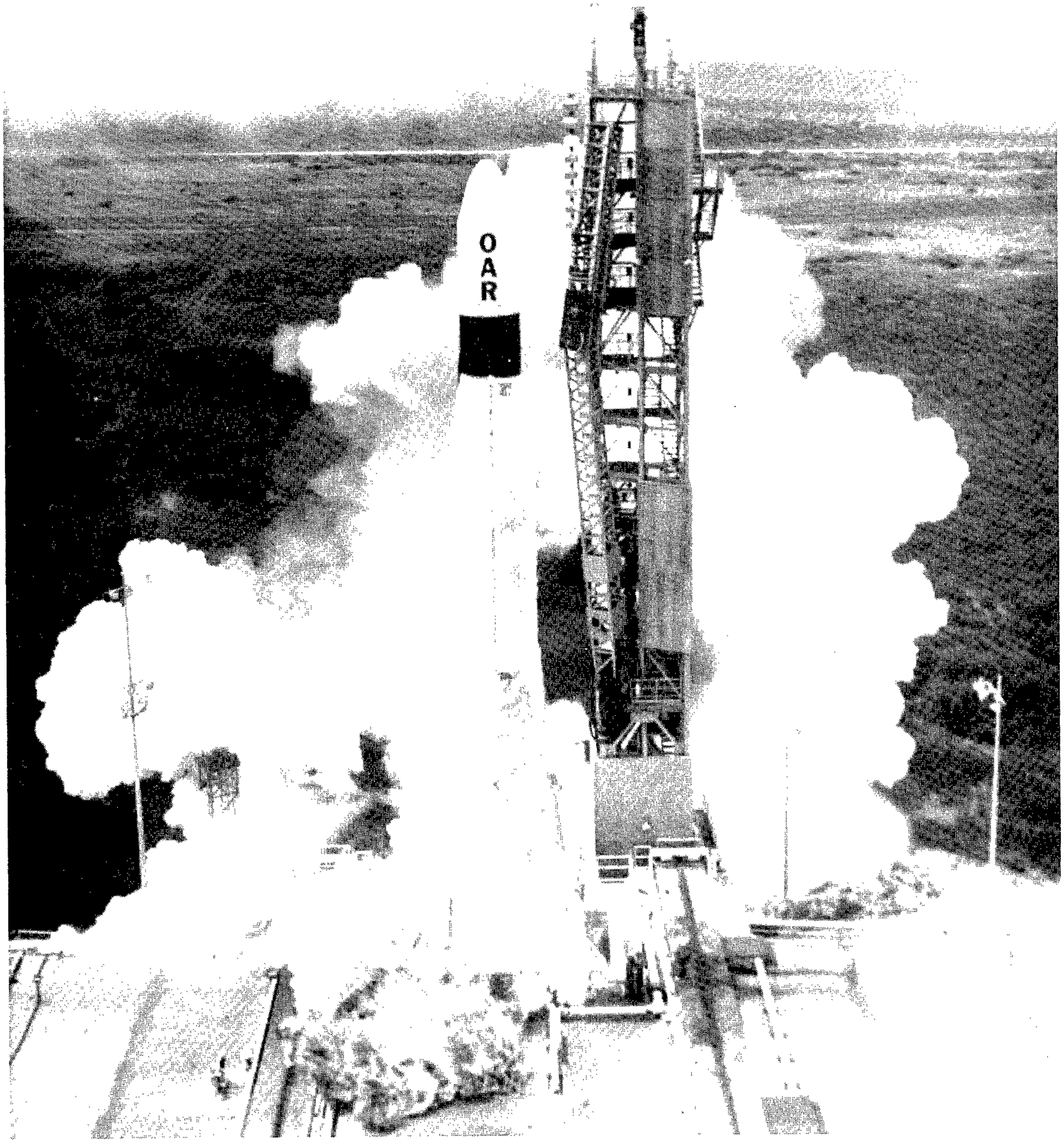

Figure 15. Satellite Launch Containing AFCRL Experiments from Vandenberg AFB, California in 1968.

and also several satellites dedicated entirely to its experiments. In this report only a few experiments in which I was involved are reviewed. (For a more complete list of AFGL satellite experiments see: *Satellite And Space Shuttle Experiments Flown By The Geophysics Directorate And Other Units of Phillips Laboratory,* by Ruth Liebowitz.[23]) Both the launch and experiments were successful for all those listed. Figure 14 shows a list of some of the early satellites and experiments. Figure 15 shows a typical satellite launch from Vandenberg AFB, California in 1968.

As with instruments on rockets, some of the earliest sensors on satellites were pressure or density sensors. J. McIsaac had pressure gauges on several early satellites. A sample of data from a gauge on OV3-6 is shown in Figure 16. This shows the raw pressure data before it is converted into atmospheric data by calculating the effect of angle of attack (zero degrees is the satellite ram direction), and correcting for gauge absorption or outgassing as its altitude changes during its orbit. The gauge pressure is highest when it is near the ram direction. It is lower at night in polar regions than at lower latitudes and in the day. The slow outgassing effect can be seen with the small decrease with time (left to right in the figure).

13.2 The Cannon Ball Satellites

Figure 17 shows a photograph of Cannon Ball I (OV1-16). The longer (retractable) antennas are for the telemetry, the two small antennas are for the radar tracking beacon, and the small cylindrical rods are for mounting. The thermal condition of the satellite was of some concern due to heating by sunlight and by atmospheric heating when orbiting at low altitude. Thus it was decided to paint the sphere black (to increase radiation) with some gold-plated circular areas. Figure 18 shows a sketch of the interior of the sphere.

The key instrument consists of three mutually perpendicular linear Miniature Electrostatic Accelerometers (MESA) developed by the Bell Aerospace Corporation, Buffalo, NY. An exploded view of one of the instruments is shown in Figure 19. The proof mass is centered radially and longitudinally by electric fields. The required strength of the longitudinal field is a measure of the acceleration component in that direction.

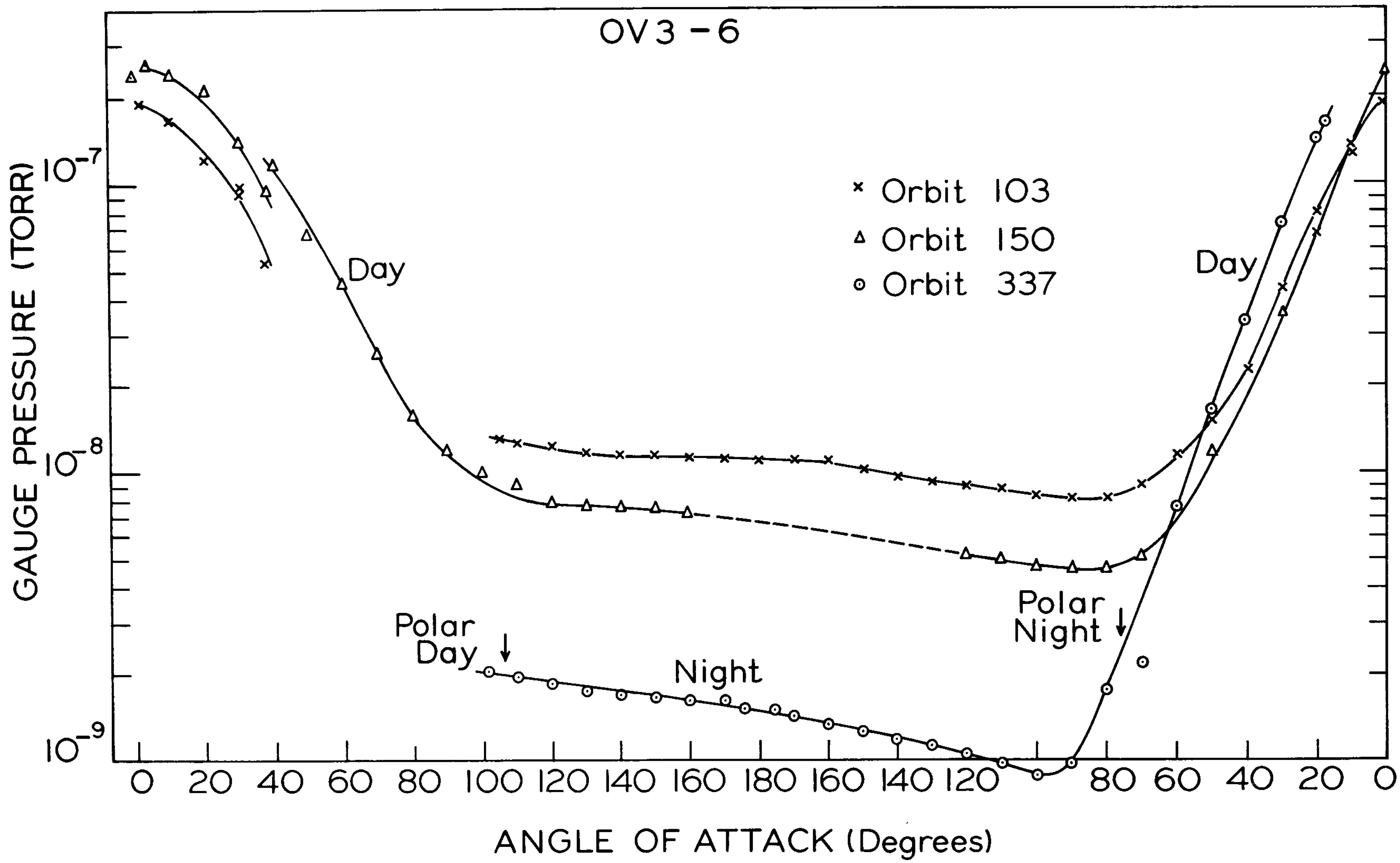

Figure 16. Pressure Gauge Measurements from OV3-6 in 1968. The figure shows the raw pressure data before it is corrected for changes with angle of attack and the effects of gauge absorption and outgassing as its altitude changes during each orbit.

Figure 17. Photograph of Cannon Ball I (OV1-16). The longer (retractable) antennas are for telemetry, the two small antennas are for a radar tracking beacon, and the small cylindrical rods are for mounting. The satellite temperature was controlled by making use of radiation. Thus the sphere was painted black except for a number of gold-plated circular areas.

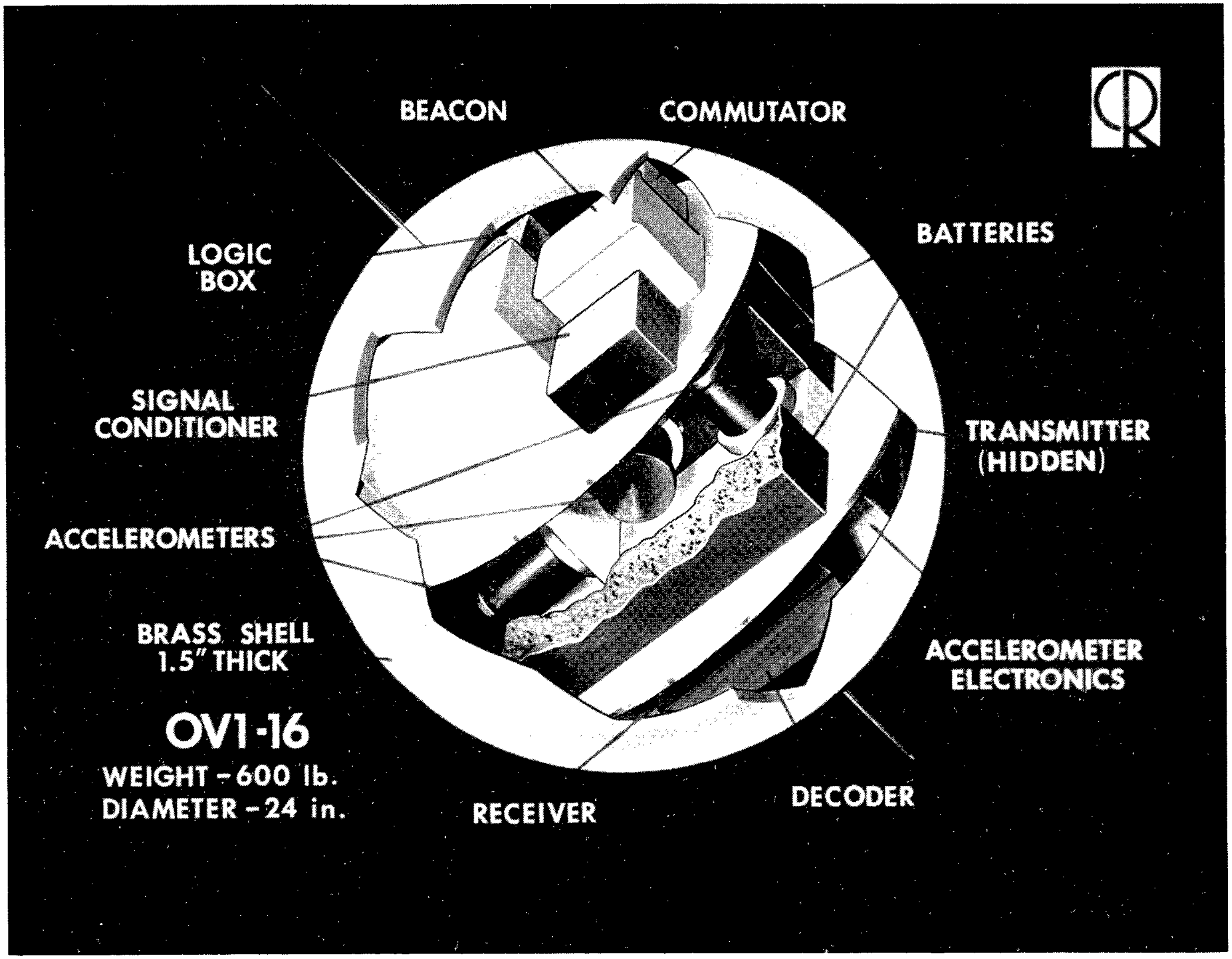

Figure 18. A Sketch of the Interior of Cannon Ball I. The key instrument consisted of three mutually perpendicular linear MESA (Miniature Electrostatic Accelerometers).

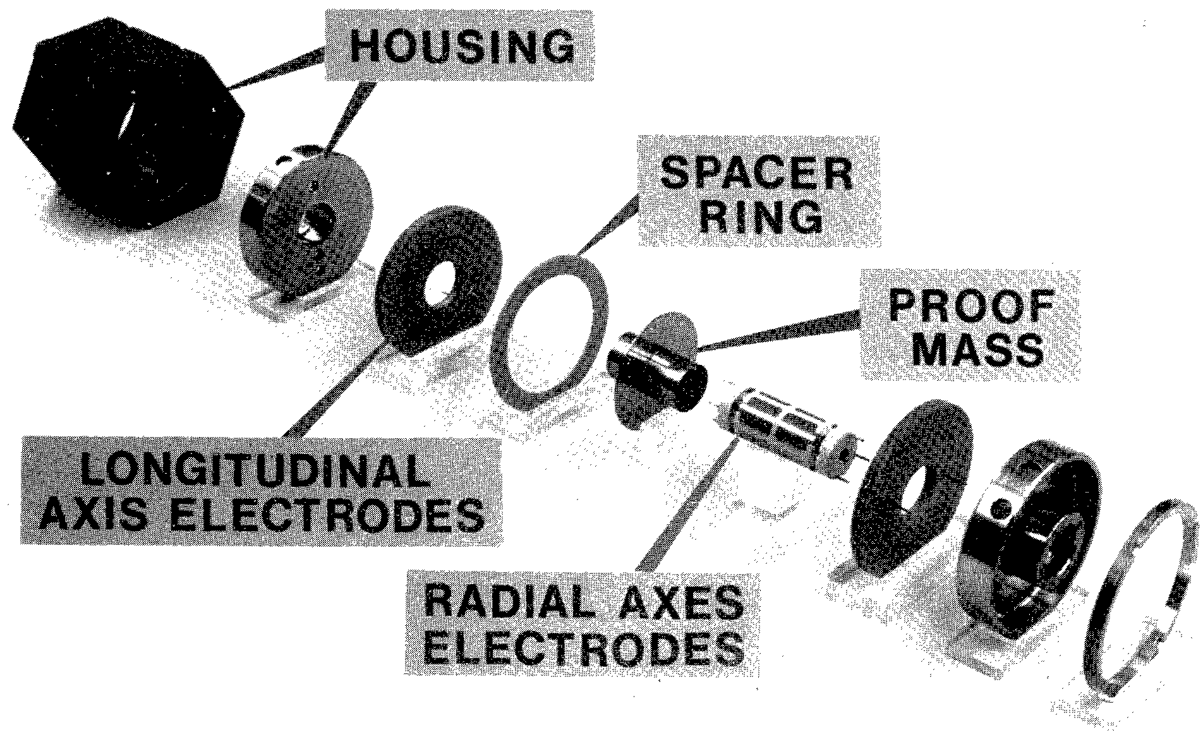

Figure 19. The Miniature Electrostatic Accelerometer Mechanical Assembly is shown. The proof mass is supported radially and longitudinally by electric fields. The strength of the longitudinal field required to center the proof mass provides a measure of the acceleration component in that direction.

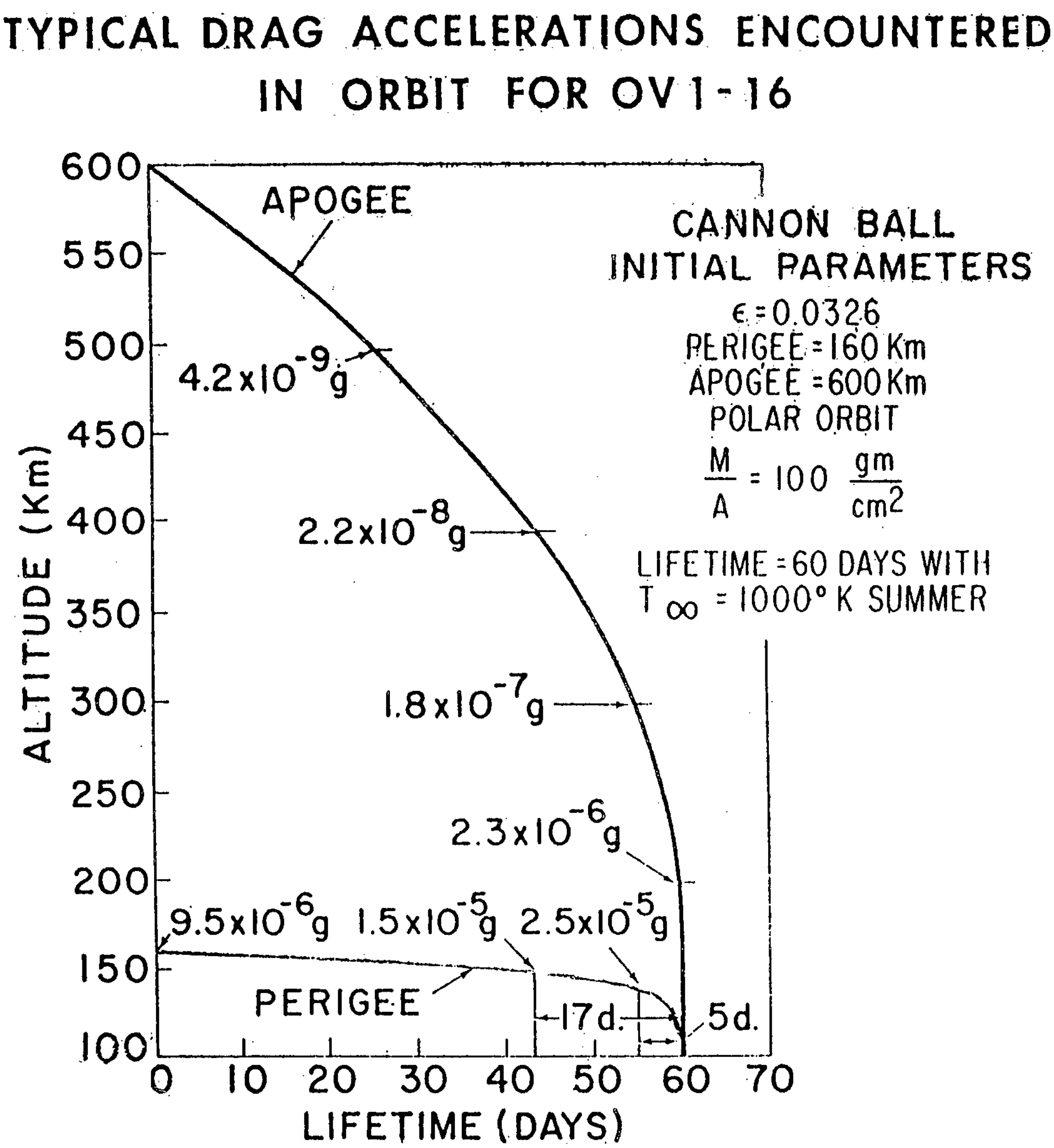

Figure 20. Drag Accelerations for Cannon Ball I Calculated Using a Thermospheric Model with an Exospheric Temperature of 1000K, and with an Initial Perigee Altitude of 160 km.

The whole, unique concept of the Cannon Ball satellites[24] was to have as large a mass/area ratio as possible so that they could stay in orbit at lower altitudes than conventional satellites and thus measure atmospheric properties in the lower thermosphere, a region of the atmosphere whose variability is largely unknown. Thus Cannon Ball I was made very small, with a diameter of only 24 inches, but a total weight of 600 lb. due primarily to a 1.5 inch thick shell of brass. Figure 20 shows typical accelerations for Cannon Ball I calculated with a thermosphere model with an exospheric temperature of 1000 K and an initial perigee altitude of 160 km. Measurements were made with drag accelerations in the range 5×10^{-5}g to 1×10^{-7}g. In principle, accelerations could be measured down to 10^{-8}g (or lower) but, in practice, the lower limit of useful data is set by data noise, imperfect location of the accelerometers, and vehicle rotation.

Figure 21 shows data from Cannon Ball I during the period 1-18 August 1968. The two lower plots show values of $F_{10.7}$ and K_p, which were used as inputs to the thermospheric models used for comparison with the densities derived from orbital drag on Cannon Ball I in the top plot. The models used for comparison were from the U.S. Standard Atmosphere Supplements 1966. It can be seen that the early density values are less than the model values, the intermediate values are about the same, and the later values are higher. There are two likely reasons for these results: one is that the perigee altitude decreases from 150 km to 128 km during this period and it is possible that the model dependence of density with altitude is not accurate; the other is that the solar flux and geomagnetic activity increase markedly during the period and the dependence of the model on these parameters is not correct.

Another satellite launched by the same vehicle as Cannon Ball I was OV1-15 or SPADES[25], a photo of which is shown in Figure 22. It contained a number of instruments, including an accelerometer and ionization gauge to measure density and a mass spectrometer to measure atmospheric composition. A considerable amount of useful data was obtained from these instruments but none at the very low altitudes at which Cannon Ball I was able to remain in orbit.

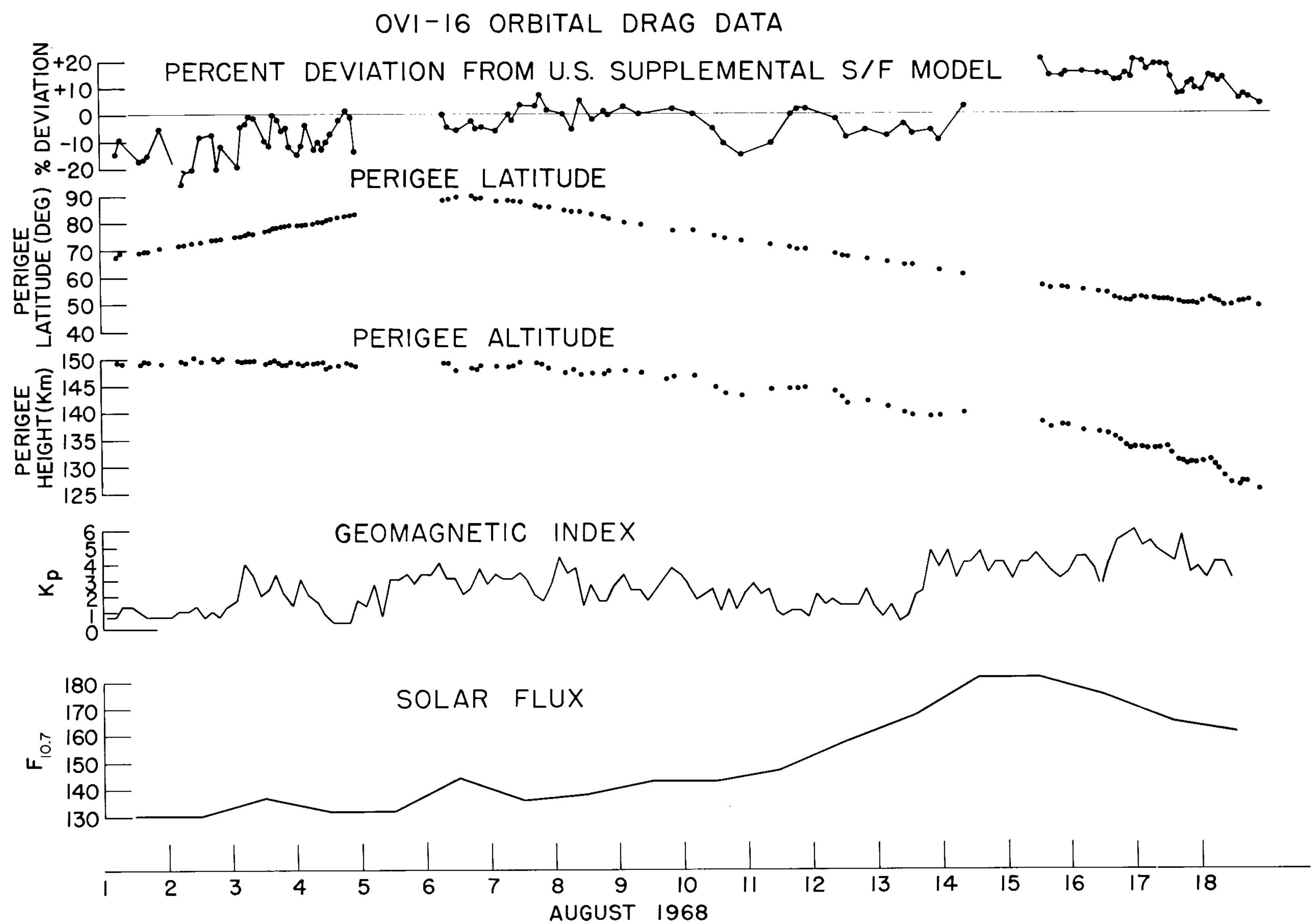

Figure 21. Data from Cannon Ball I During the Period 1-18 August 1968. The two lower plots show values of $F_{10.7}$ and K_p which were used as inputs to the thermospheric models used for comparison with the measured densities.

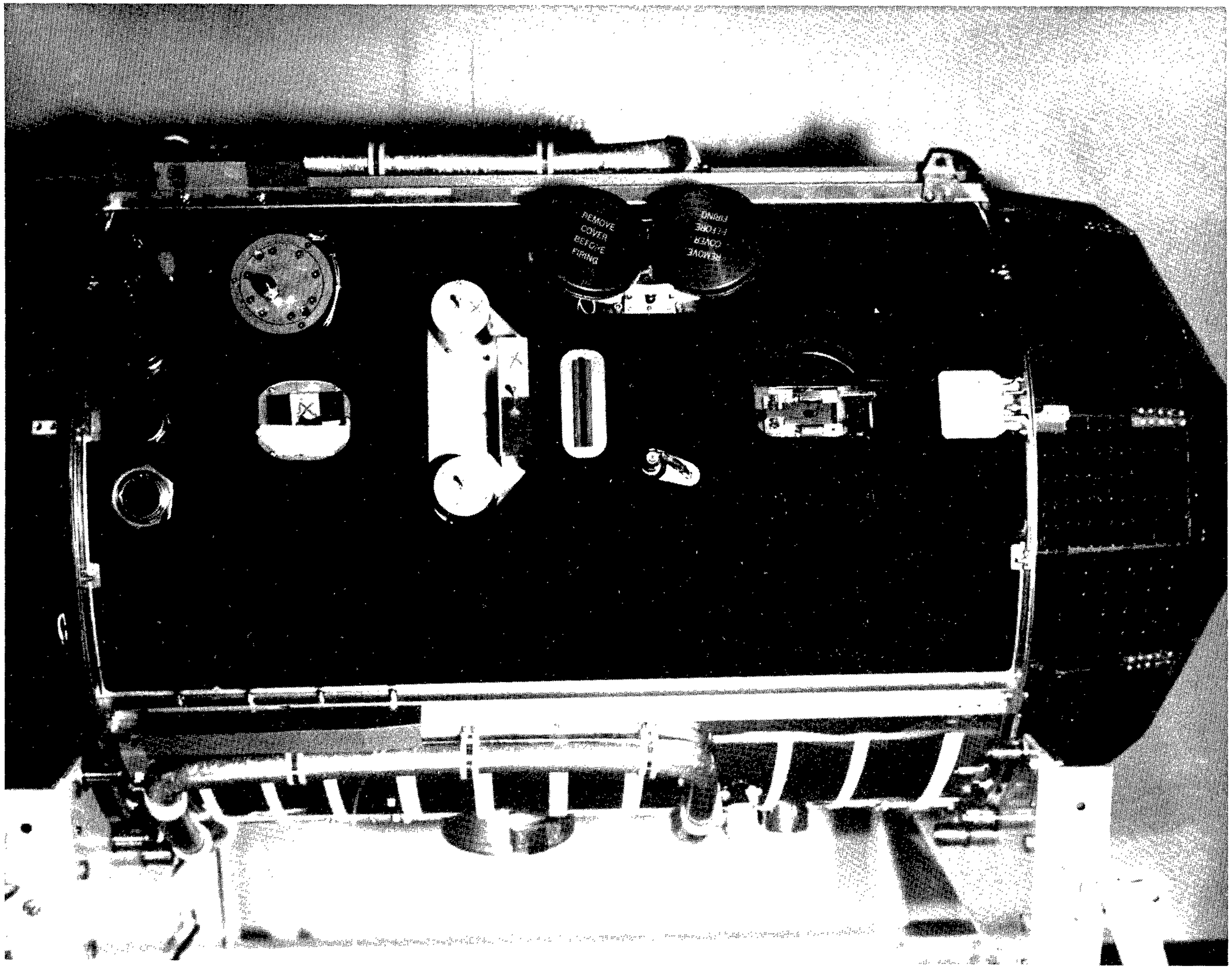

Figure 22. Photograph of SPADES (OV1-15) Satellite Launched at the Same Time as Cannon Ball I (OV1-16).

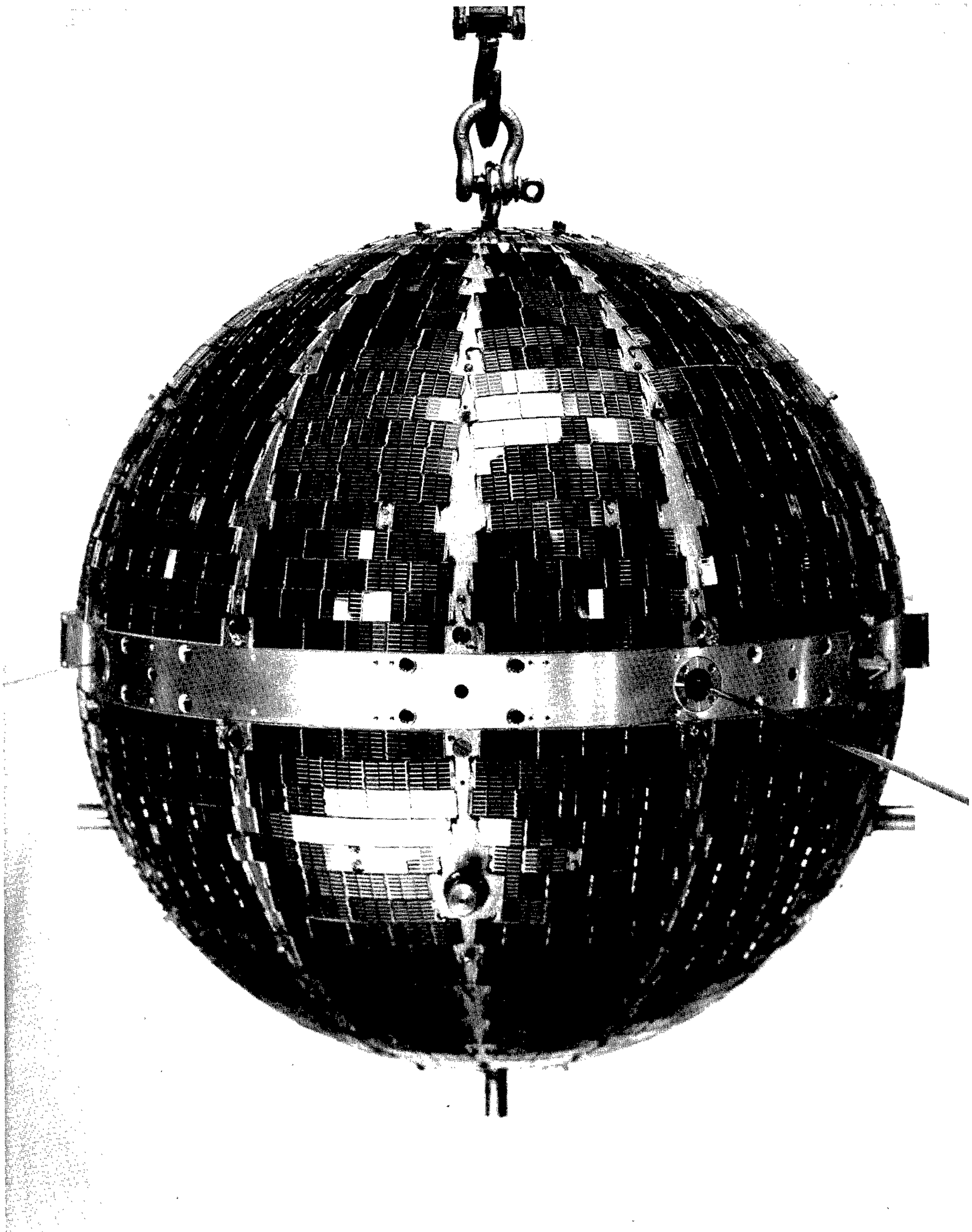

Figure 23. Photograph of Cannon Ball II (OV1-20). It was similar to Cannon Ball I, but larger and heavier and had solar cells on its surface to provide power for a longer period than the batteries in Cannon Ball I.

A group of three satellites was put into orbit on 7 August 1971. They were OV1-20 (Cannon Ball II[26] and Musket Ball[27]) and OV1-21 DENPER. Cannon Ball II was similar in concept to Cannon Ball I but larger and heavier and had solar cells on its surface (Figure 23) to provide power for a longer period than the batteries used in Cannon Ball I. Musket Ball was similar to Cannon Ball I but smaller. It contained a radar tracking beacon but no accelerometer. DENPER contained similar experiments to SPADES. Very good data were obtained from all three satellites. The Cannon Ball satellites hold the record for the lowest altitude orbital in situ measurements of atmospheric properties.

13.3 The S3 Multi-Measurement Satellites

Figure 24 contains a list of 4 more satellites. The first was S3-1, launched in 1974. A schematic of the satellite and the instruments it contained is shown in Figure 25. There were 12 instruments on it. They included 3 density gauges, 2 accelerometers, 2 mass spectrometers, and VLF, retarding potential analyzer, electrostatic analyzer, magnetometers and solar ultraviolet instruments. Figure 26 shows a photograph of a magnetically controlled ionization density gauge. To minimize outgassing problems while in orbit, the gauge is evacuated and sealed before launch. When in orbit the cap at the right of the photo is opened and atmospheric measurements are started. A sketch of the S3-1 satellite is shown in Figure 27. It was spin-stabilized about the axis as shown in the figure. The VLF antennas, magnetometers, and telemetery antennas can also be seen.

Figure 28 shows the instruments flown on satellite S3-2. Some of the instruments were the same as on S3-1, but there were some important differences. The VLF and solar ultraviolet instruments were omitted and planar ion and electron traps, electric field, and energetic particle sensors were added. A great deal of useful data was obtained from both the S3-1 and S3-2 satellites.

13.4 Atmosphere Explorer Satellites

When NASA was planning the Atmosphere Explorer -C, -D, and -E satellites they decided to use the AFGL expertise with solar Extreme Ultraviolet (EUV) instruments and measurements of Hans Hinteregger, and the experience with low altitude satellites and density measurements with the Cannon Ball and other satellites of my group. The concept

LAUNCH DATE	SATELLITE	SCIENTIST	EXPERIMENT
1974	S3-1	F. MARCOS	SINGLE-AXIS & PIEZOELECTRIC ACCELEROMETERS
		R. PHILBRICK	IONIZATION GAUGE & MASS SPECTROMETER
1976	S3-2	R. PHILBRICK	IONIZATION GAUGE & MASS SPECTROMETER
		F. MARCOS	(PIEZOELECTRIC ACCELEROMETER-FAILURE)
16 DECEMBER 73	AE-C	H. HINTEREGGER	SOLAR EUV SPECTROMETER
		K. CHAMPION	TRIAXIAL ACCELEROMETER
6 OCTOBER 75	AE-D	H. HINTEREGGER	SOLAR EUV SPECTROMETER
		K. CHAMPION	TRIAXIAL ACCELEROMETER (REENTERED EARLY)

Figure 24. Contains a list of Four Satellites Launched Between 1973 and 1976. They were S3-1 launched in 1974, S3-2 launched in 1976, and the NASA satellites Atmospheric Explorers, -C and -D launched respectively in 1973 and 1975.

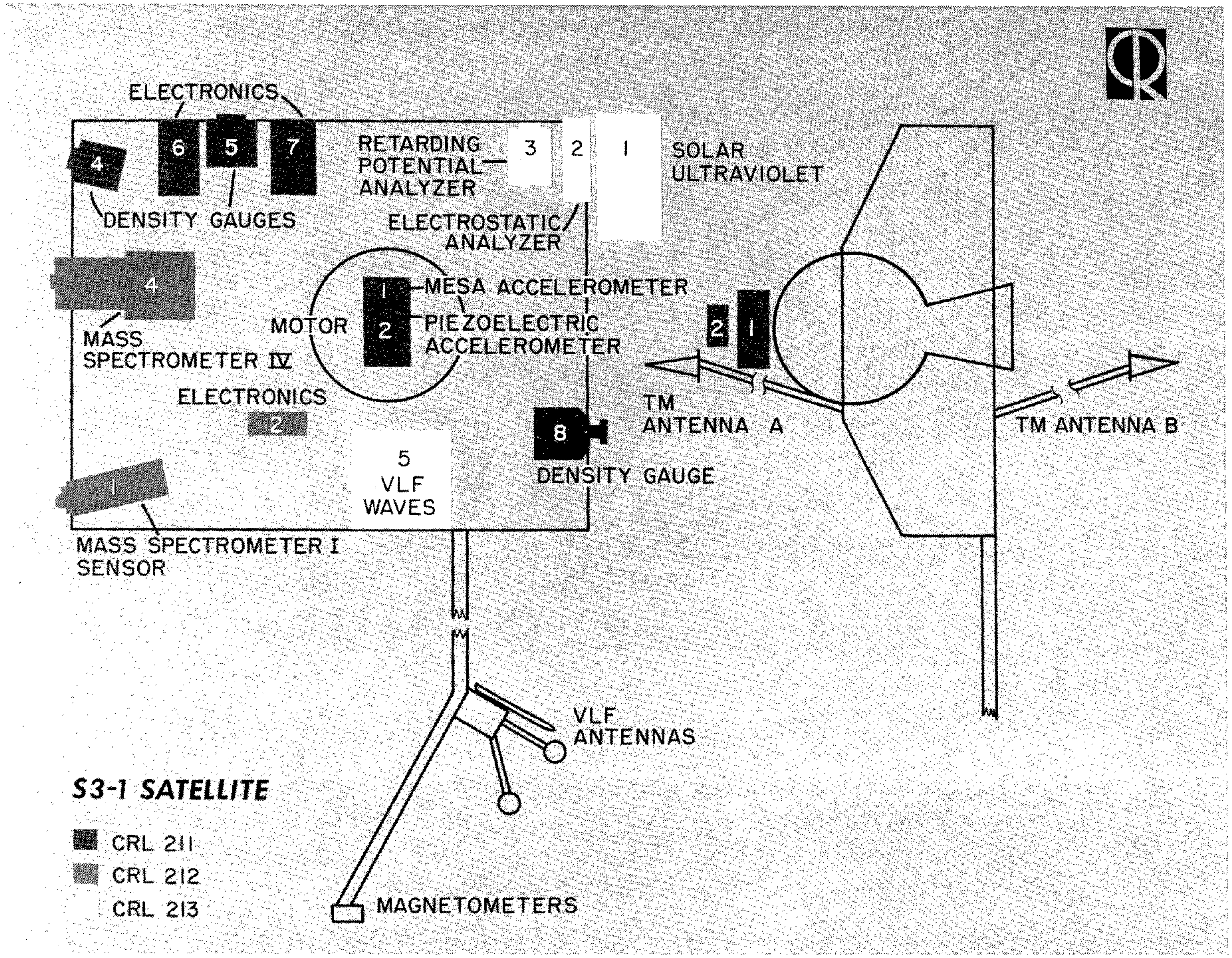

Figure 25. A Schematic of the S3-1 Satellite and the 12 Instruments that were Flown on it.

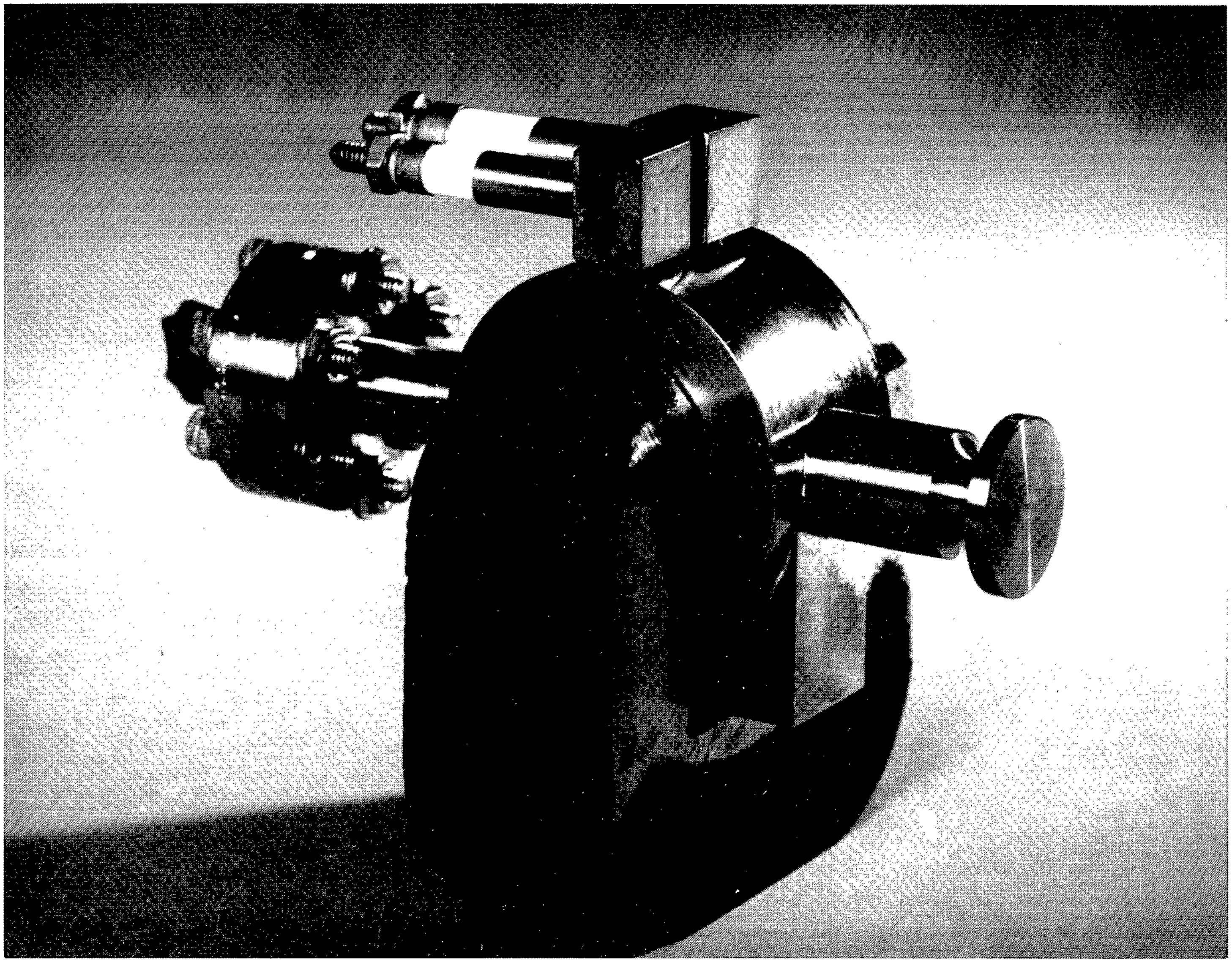

Figure 26. A Photograph of a Magnetically Controlled Ionization Gauge for Measuring Atmospheric Density. It was one of the density gauges flown on satellite S3-1.

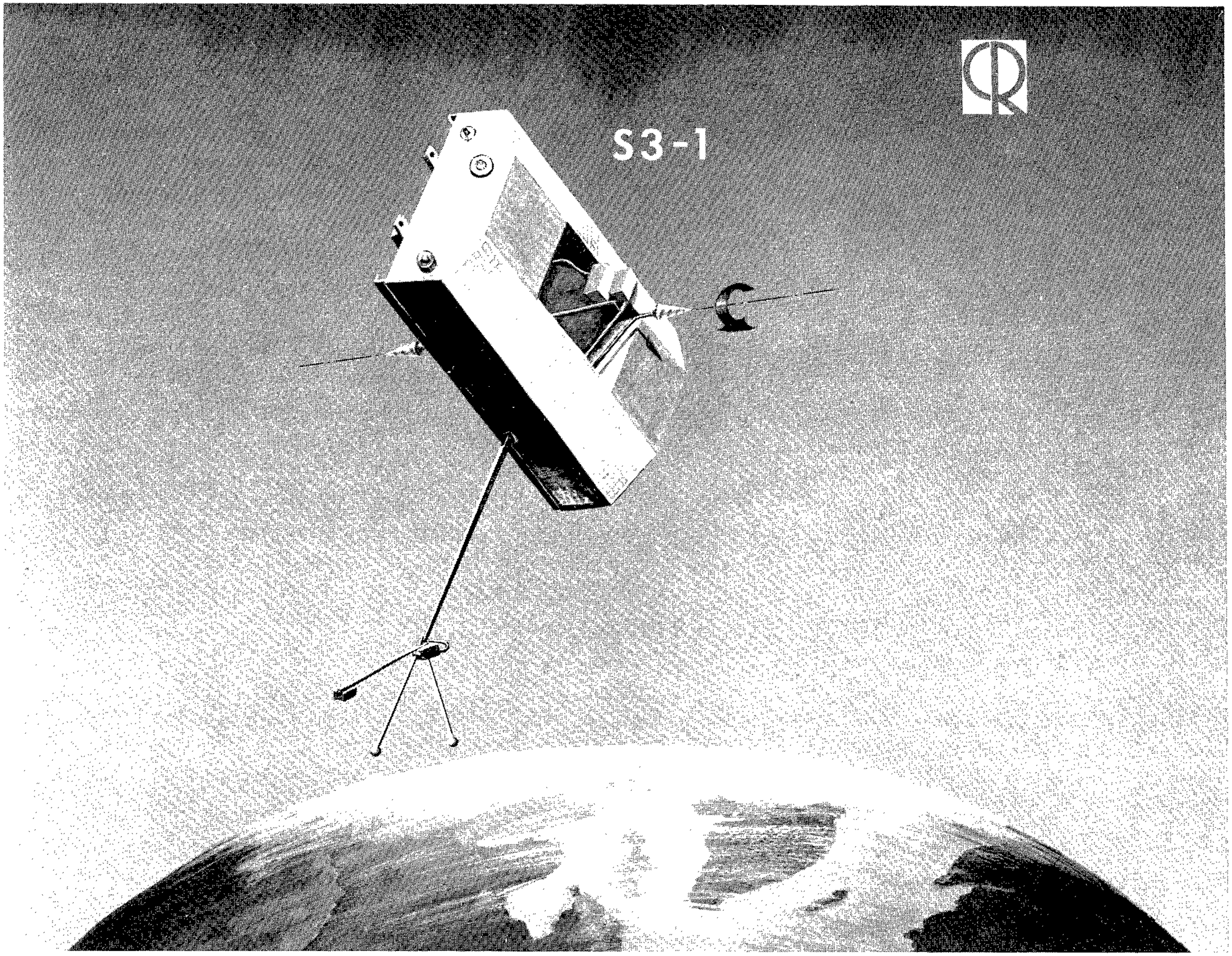

Figure 27. A Sketch of the S3-1 satellite.

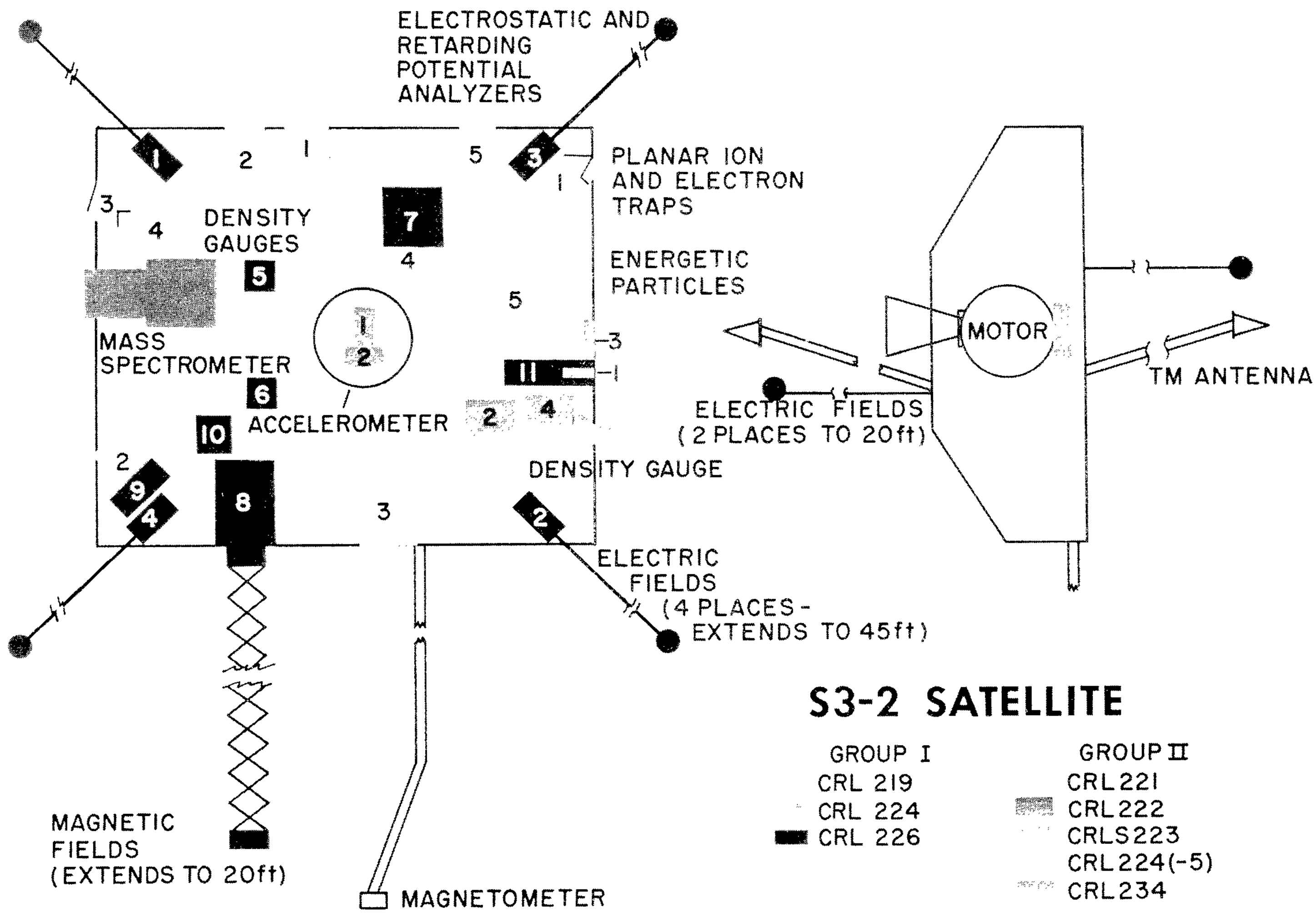

Figure 28. A Schematic of the S3-2 Satellite and the Instruments Flown on it. They were similar to the instruments flown on S3-1, but the VLF and solar ultraviolet instruments were omitted and ion and electron traps, electric field and energetic particle sensors were added. These instruments added useful additional information on the properties of the upper atmosphere and ionosphere.

of the series of Atmosphere Explorer satellites was to have the capability of using thrusters to change their apogees and perigees. One of the goals was to lower the perigees to relatively low altitudes (about 130 km) but not as low as the Cannon Ball series (about 105 km), altitudes in the thermosphere. There were two reasons to limit the lowest altitudes. One was to eliminate the possibility of premature reentry due to drag effects on the satellites and the other was to eliminate the possibility of damage to the satellites and exposed instruments due to excess heating by the atmosphere at low orbital altitudes.

There were about 15 experiments on each Atmospheric Explorer satellite. Although the whole program was managed and primarily funded by NASA the instruments were provided by various organizations, including universities and industry. NASA set up a scientific team including the Principal Investigators of each experiment and several theoreticians. Figure 29 contains a cartoon sketch of the members of the Science Team, plus several other people who were significant participants in the Program. Hans Hinteregger of AFGL is shown next to the Sun because of his work in measuring solar ultraviolet radiation, which is important in heating and ionizing the upper atmosphere. To the left of Hans is Alec Dalgarno, a theoretical physicist from Harvard University. I am at the bottom left of the sketch, as Principal Investigator for the MESA experiment, which measures drag acceleration on the spacecraft. Atmospheric density and winds can be derived from these data. In the center of the sketch (below Hinteregger) is the cartoonists concept of the Atmosphere Explorer satellite and below that, in a semi-recumbent position, is Nelson Spencer, the NASA Principal Investigator for this series of satellites. Other experiments on this series of satellites included C.A. Barth (NO measurements), A.O. Nier (open mass spectrometer), D.T. Pelz (closed mass spectrometer), P. Hayes (airglow), L.H. Brace (cylindrical probes), W.B. Hanson (planar traps), J.P. Doering (photo electrons), J.H. Hoffman (magnetic ion spectrometer), J. Armstrong (magnetic field), H. Brinton (Bennett ion spectrometer), R. Hoffman (particle experiment), and D.Figure Heath (EUV filter photometer). The series was extremely

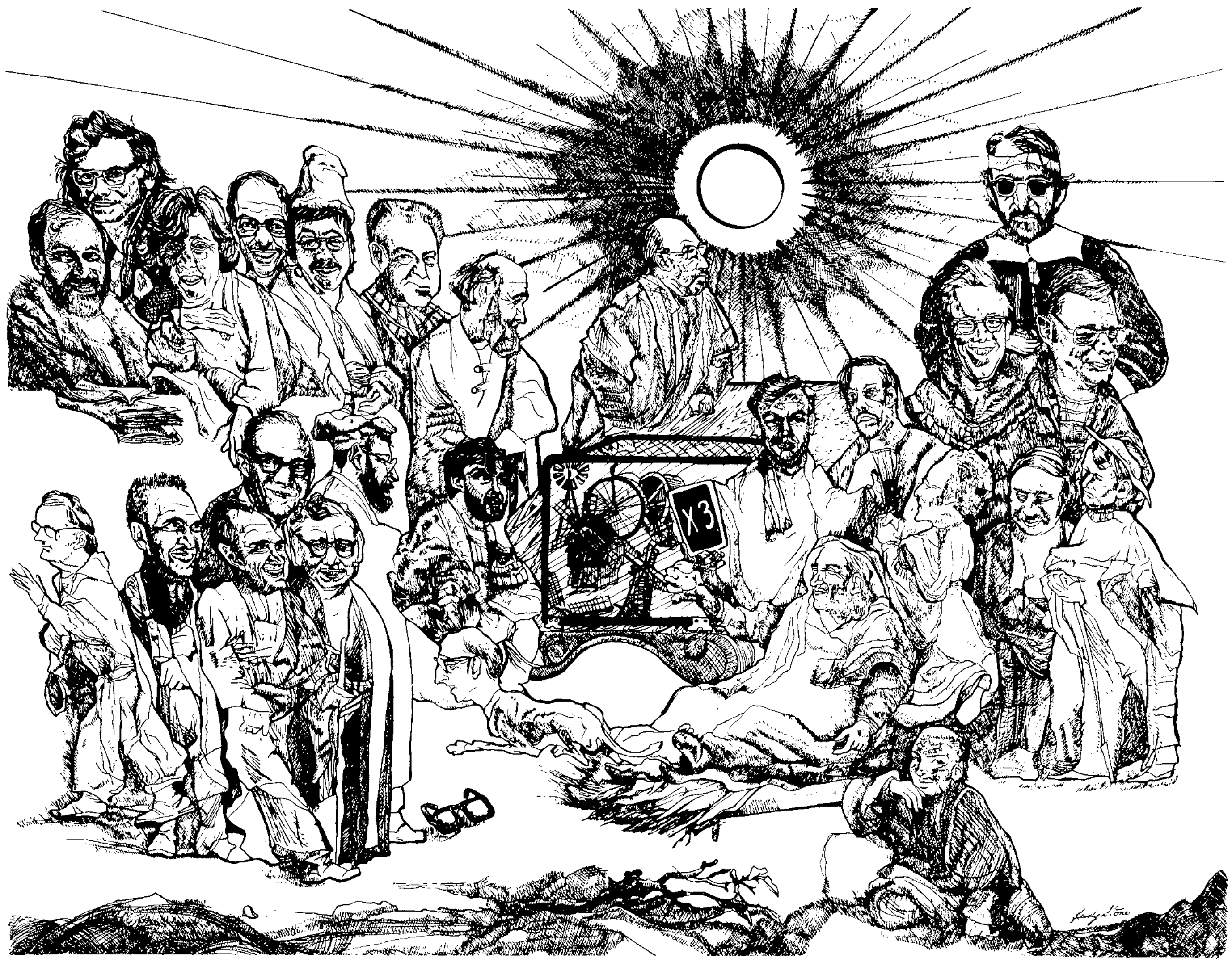

Figure 29. Sketch of the NASA Atmospheric Explorers -C, -D, & -E Science Team, plus Several Other Significant Participants in the Program. Those in the sketch include H. Hinteregger, A. Dalgarno, W. Hanson, P. Hayes, A. Hedin, C. Reber, N. Spencer, A. Nier, and myself.

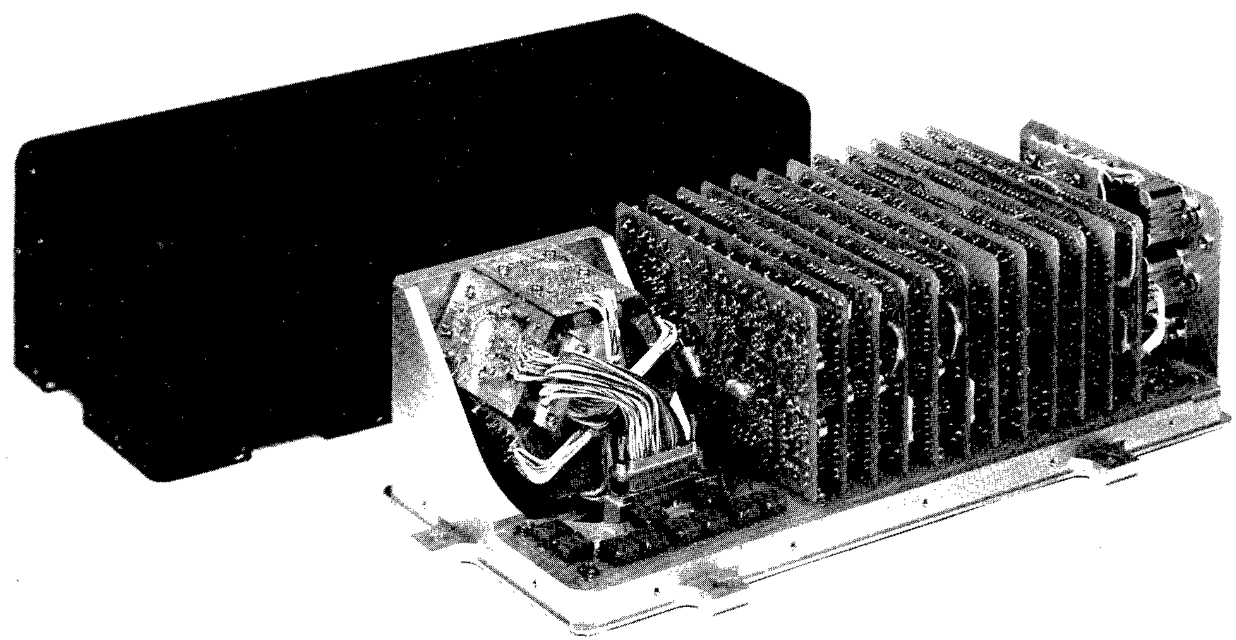

Figure 30. The MESA Triaxial Instrument and Associated Electronics as Flown on the AE Satellites and on a Number of Air Force Satellites. The accelerometers are housed in the hexagonal-shaped container at the left.

LAUNCH DATE	SATELLITE	SCIENTIST	EXPERIMENT
20 NOVEMBER 75	AE-E	H. HINTEREGGER K. CHAMPION	SOLAR EUV SPECTROMETER TRIAXIAL ACCELEROMETER (OPERATED UNTIL 6 OCT 81)
1978	S3-4	R. HUFFMAN F. MARCOS	UV BACKGROUNDS DENSITY ACCELEROMETERS
1 JANUARY 79	SCATHA	C. PIKE H. COHEN	SPACECRAFT CHARGING PARTICLE FLUXES AND ELECTRIC FIELDS ACTIVE DISCHARGES (USED A BEAM TECHNIQUE HE HAD DEVELOPED TO USE ON ROCKETS TO MEASURE DENSITY)
1979	SETA 1	F. MARCOS	TRIAXIAL ACCELEROMETER
1982	SETA 2	F. MARCOS	TRIAXIAL ACCELEROMETER
1983	SETA 3	F. MARCOS	TRIAXIAL ACCELEROMETER

Figure 31. Some Additional Satellites on which AFGL Instruments were Flown. The SCATHA satellite was instrumented to study the phenomenon of spacecraft charging of satellites in orbit. The SETA sensor was a modified MESA in which accelerations could be detected in all directions using a single instrument.

productive and resulted in an important enhancement of our understanding of the thermosphere and ionosphere.

13.5 Some Additional Satellites

Figure 30 shows a photograph of the MESA (Miniature Electrostatic Accelerometer) triaxial instrument and associated electronics which was flown on three Atmosphere Explorers[28] and on a number of Air Force satellites. Frank Marcos was involved in analysis of the data from the MESA instruments on a number of satellites. The atmospheric density values measured by the MESA instruments on the Atmosphere Explorers agreed very well with the neutral composition measurements made by A.O. Nier's mass spectrometers[29].

Figure 31 lists some additional satellites on which AFGL instruments were flown. H. Cohen had developed an electron beam device that was flown on a rocket to measure neutral atmospheric density by measuring backscattered bremsstrahlung. He subsequently installed this device on the SCATHA satellite to control the electric change on the satellite. Frank Marcos flew a SETA (Satellite Electrostatic Triaxial Accelerometer)[30] on a number of Air Force satellites. The data from these measurements resulted in a better understanding of the properties of the upper atmosphere and more accurate satellite navigation.

14. CONCLUSION

This report covers some of the important research activities of the Air Force Cambridge Research Center, Geophysics Research Directorate (and its successor organizations) during its first 40 years of existence. It has achieved some spectacular successes. These include: Investigations of the upper atmosphere using high altitude releases of various chemicals. Contributions to the development of U.S. Standard atmospheres and to COSPAR International Reference Atmospheres. Satellite measurements of upper atmosphere properties, including those by the unique low altitude Cannon Ball satellites.

REFERENCES

1. Marmo F.F., Pressman J., Aschenbrand L.M., Jursa A., and Zelikoff M., (1956) Formation of an Artificial Ion Cloud; Photoionization of NO by Solar Lyman Alpha at 95 km, ***J. Chem. Phys.***, **25**, (1): 187

2. Pressman J., Aschenbrand L.M., Marmo F.F., Jursa A., and Zelikoff M. (1956) Synthetic Atmospheric Chemiluminescence Caused by the Release of NO at 106km, ***J. Chem. Phys.***, **25**, (1): 187

3. Jursa A.S., Nakamura M., and Tanaka Y., (1963) Molecular Oxygen Distribution in the Upper Atmosphere, ***J. Geophys. Res.***, **68**, (22): 61145

4. Hall L.A., Schweizer W., and. Hinteregger H.E. (1965) Improved Extreme Ultraviolet Absorption Measurements in the Upper Atmosphere, ***J. Geophys. Res.***, **70**, (1): 105

5. Ulwick J.C. and Blank C.A. (1970) ***Proceedings of Meeting on Operation PCA 69***, AFCRL-70-0625, AD716385

6. Champion K.S.W. and Minzner R.A., (1959) Atmospheric Densities from Satellite and Rocket Observations, ***Planet. Space Sci.***, **1**: 259

7. Minzner R.A., Champion K.S.W., and Pond H.L. (1959) ***The ARDC Model Atmosphere***, Air Force Surveys in Geophysics No. 115 (AFCRC-TR-59-267), Air Force Cambridge Res. Center

8. Minzner R.A., Ripley W.S., and Condron T.P. (1958) ***U.S. Extension to the ICAO Standard Atmosphere - Tables and Data to 300 Standard Geopotential Kilometers, Geophysics Res. Dir. and U.S. Weather Bureau***

9. Champion K.S.W. and Minzner R.A. (1962) **Proposed Revision of U.S. Standard** ***Atmosphere 90 to 700km,*** AFCRL-62-802, Air Force Cambridge Res. Labs

10. Champion K.S.W. and Minzner R.A. (1963) ***Revision of U.S. Standard Atmosphere 90 to 700km,*** Rev. Geophys., 1:57

11. Champion K.S.W., O'Sullivan W.J., and Teweles S.(eds.) (1962) ***U.S. Standard Atmosphere, 1962,*** NASA, USAF and USWB, U.S. Govt. Printing Office

12. Champion K.S.W., O'Sullivan W. J., and Woolf H.M. (eds.) (1966) ***U.S. Standard Atmosphere Supplements,*** 1966, ESSA, NASA and USAF, U.S. Govt. Printing Office

13. Champion K.S.W. (1965) U.S. Supplementary Atmospheres, ***Proc. 12th Annual Air Force Science and Engineering Symp.,*** Oct. 1965, and AFCRL-66-564, 1966, AD640265

14. Minzner R.A., Reber C.A., Champion K.S.W., Moe O.K., Nier A.O., Swenson G.R., and Zimmerman S.P. (1974) ***Final Report of Task Group II to COESA,*** NASA X-911-47-366

15. Kantor A.J., Minzner R.A., and Quiroz R.S. (eds.) (1976) ***U.S. Standard Atmosphere,*** 1976, NOAA, NASA and USAF, U.S. Govt. Printing Office

16. COSPAR Working Group IV, (1965) ***COSPAR International Reference Atmosphere (CIRA) 1965,*** North Holland Publ. Co.

17. COSPAR Working Group 4 (1972) ***COSPAR International Reference Atmosphere (CIRA) 1972,*** Akademie-Verlag, Berlin

18. Rees D. (ed.) (1989) ***COSPAR International Reference Atmosphere (CIRA) 1986, Part I Thermosphere Models, Adv. Space Res.*** **8,** (5-6)

19. Rees D., Barnett J.J., and Labitzke K. (eds.) (1990) ***COSPAR International Reference Atmosphere (CIRA) 1986, Part II Middle Atmosphere Models, Adv. Space*** Res. **10,** (12)

20. Bilitzka D. (1994) IRI: An International Rawer Initiative, ***Adv. Space Res.*** 15, (2)

21. Rawer K., Lincoln J., and Conkright R.(eds.) (1981) ***International Reference Ionosphere, IRI 79,*** Report UAG 82, WDCA for Solar-Terrestrial Physics, Boulder, CO

22. Bilitzka D. (ed.) (1990) ***International Reference Ionosphere 1990,*** NSSDC/WDC-A-R&S 90-22, Greenbelt, MD

23. Liebowitz Ruth; (1995) ***Satellite and Space Shuttle Experiments flown by the Geophysics Directorate and other Units of Phillips Laboratory at Hanscom AFB, MA and by their Predecessor Organizations, 1958-1994,*** PL-TR-95-2010, Special Reports, No. 273

24. Champion K.S.W., Marcos F.A. and Schweinfurth R.A. (1970) Measurements by the Low Altitude Density Satellite OVI-16, ***Space Research*** **10**: (459).

25. Champion K.S.W., Marcos F.A., and McIsaac J.P.; (1970) Atmospheric Density Measurements by the Research Satellite OVI-15, ***Space Research* 10**: 450

26. Marcos F.A., and Champion K.S.W. (1973) Lower Thermospheric Density Variations Determined from Accelerometers on the Cannon Ball II Satellite, ***Space Research* 13**: 229

27. Champion K.S.W., Marcos F.A., and Schweinfurth R.A. (1973) Atmospheric Density Values from Orbital Drag on the Cannon Ball II and Musket Ball Satellites, ***Space Research* 13**: 223

28. Marcos F.A., Garrett H.B., Champion K.S.W., and Forbes J.M. (1977) Density Variations in the Lower Thermosphere from Analysis of the AE-E Accelerometer Measurements, ***Planet and Space Sci.*, 25**: 499

29. Marcos F.A., Champion K.S.W., Potter W.E., and Kayser D.C. (1977) Density and Composition of the Neutral Atmosphere at 140km from Atmosphere Explorer-C Data, ***Space Research* 17**: 321

30. Marcos F.A., and Forbes J.M. (1985) Thermospheric Winds from the Satellite Electrostatic Triaxial Accelerometer System, ***J. Geophys. Res.* 90**: 6543